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PROGRESS OF SPACE RESEARCH 1989-1990

Report submitted by the Committee on Space Research of the International Council of Scientific Unions

Note by the Secretariat

Annexed hereto is a report on the progress of space research in 1989-1990, submitted by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) in accordance with the request of the Scientific and Technical Sub-Committee for the submission of reports by COSPAR on scientific and technological developments in the exploration and peaceful uses of outer space.

The report was edited by Dr. Karen Plain-Switzer based on the contributions of distinguished scientists representing the COSPAR Interdisciplinary Scientific Commissions and Panels. The contributing scientists are listed in the appendix. The report was transmitted by Dr. William Ian Axford, President of COSPAR. The report is being circulated, as received, only in the language of its submission (English).

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Annex

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CHAPTER ONE

SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

1. RESEARCH ACTIVITIES

1. Meteorology and climatology of the lower atmosphere including fundamental dynamical processes in the oceans.

1.1 The Earth Radiation Budget

The Earth Radiation Budget Experiment (ERBE) data set (now interrupted by the failure of the last ERBE scanner in early 1990) constitutes a unique collection of top-of-the atmosphere radiation fields including clear-sky fluxes and albedo. The availability of these clear-sky fields permits one to consider the cloud radiative forcing diagnostic. Comparisons between the ERBE data and sophisticated General Circulation Models (GCM's) have been conducted. The results are indicative of our skill in modeling clouds occurrence, structure, geographical and vertical distribution, and radiative properties. By now it is clear that the ERBE data set offers unprecedented opportunities, not only for describing the radiative fluxes at the top of the atmosphere in short and long wavelength ranges, but also for studying very basic physical processes including the cloud radiative forcing. Because these data can now be compared with outputs from global models, they give new perspectives regarding the needed model improvements, which is one of the keys for a better understanding of clouds feedback effects with respect to climatic change issues. In addition to using ERBE data in connection with global scale problems, they are also employed for regional studies dealing with the diurnal cycles of the outgoing short and longwave radiation.

The French-Soviet ScaRaB (Scanner Radiatsionnovo Balansa) experiment alternates with the ERBE for the monitoring of the Earth radiation balance. The beginning of this experiment is scheduled for 1991 and the instrument is planned for flight on a continuous series of Soviet Meteor-type satellites.

1.2 Clouds and Soundings in the Troposphere.

Clouds are of primary interest for meteorology including weather prediction and, as indicated above, for climate studies. Research in this field is mostly done within the frame of the International Satellite Cloud Climatology Project (ISCCP), which includes various regional experiments such as the International Cirrus Experiment of Western Europe (ICE). These experiments offer good opportunities for testing new technology such as the lidar instruments. The two main topics which can be identified in cloud studies concern cloud detection and classification, and the modeling of cloud fields with respect to their vertical and horizontal morphology, their liquid water and ice contents and obviously, their interactions with radiation. NOAA/NESDIS has developed an algorithm for remote sensing of global cloud cover using multi-spectral radiance measurements from the Advanced Very High Resolution Radiometer (AVHRR). It is intended that this algorithm will be implemented into the operational data processing scheme. Much work still needs to be done in order to understand and to model the scale interactions inside the cloud, and between the cloud field and its environment. It is now recognized that clouds are a very heterogeneous media in terms of their microphysical contents in rain droplets and ice crystals, as well as in terms of their internal dynamics. As a first step before a physical modeling, statistical representations of cloud and cloud field heterogeneities are under development on the basis of the multifractal theory. Proposals for an extension of ISCCP and for a more comprehensive Global Energy and Water Experiment (GEWEX) have been made to the World Climate Research Program (WRCP). TRMM (Tropical Rainfall Measuring Mission, a joint US-Japan mission), BEST (Tropical System Energy Budget, a French mission concept), and the future Japanese platform JPOP, are considered as important components of a GEWEX space-based observation system.

Three-dimensional analysis of atmospheric thermodynamics using data from the TIROS Operational Vertical Sounder (TOVS) and the Special Sensor Microwave/Imager (SSM/I) on board NOAA-10, NOAA-11 and DMSP respectively, is being carried out routinely. A significant amount of work has been done to improve the efficiency of the existing algorithms in order to make them useable for global applications. Modeling efforts are performed for a complete and consistent use of data in the infrared and microwave regions. In addition to these efforts for improving the direct approach, inversion schemes are also being updated and refined. Studies dealing with the impact of satellite products on weather forecasting have also been initiated and they benefit from a rapid development of elaborated variational methods.

1.3 Biogeophysical Processes over Continental Surfaces.

In the context of ISLSCP (International Land Surface Climatology Project) significant improvements have been made in the observation, monitoring and modeling of the biogeophysical processes at the Earth's surface. The major regional experiments in this field are: the First ISLSCP Field Experiment (FIFE), the HAPEX-Mobilhy experiment and the Sahelian Energy Balance Experiment (SEBEX). Data analysis from these campaigns is not yet complete but already brings new possibilities to the modeling and remote sensing communities for calibrating detailed surface energy balance models and for developing and validating new methods for interpreting satellite data in terms of biological parameters. Clearly, the next ISLSCP experiments, namely HAPEX-Sahel and EFEDA, will greatly benefit from these improvements which must provide new insight into our knowledge about surface processes of arid and semi-arid regions.

In the frame of IGBP, there is now great interest in the dynamics of vegetation, mainly to assess the impacts of climatic variability. Such multi-disciplinary studies require strong efforts to establish urgently needed links between ecology, chemistry and physics. The Boreal Ecosystem Atmosphere Study (BOREAS) will be devoted specifically to the study of interactions between boreal forest biome and the atmosphere in order to clarify their roles in global change. The SAvannas on the Long Term (SALT) will focus on the dynamics of savannas in West Africa. These are just two examples of the various experiments now planned for the 1990's to study the biospheric aspects of the hydrological cycle and the possible feedbacks between global change and the terrestrial ecosystems.

1.4 Physical and Biological Processes in the Ocean

Studies of ocean dynamics are developing rapidly due to the availability of satellite altimetry data provided by GEOSAT before its failure in March 1990. The use of inverse techniques for extracting the mean sea surface and the tidal components appears to be very promising. Simultaneously, data from the microwave radiometers SMMR on the Nimbus 7 satellite, together with the SSM/I on the DMSP satellite, (and ATSR/M in the near future) are used to measure the wind stress at the surface of the oceans. Significant improvements in these fields will serve the ERS 1 and Topex/Poseidon missions giving a new impulse to oceanography, in particular in the context of the World Ocean Circulation Experiment (WOCE). The Topex/Poseidon altimetric mission will yield highly accurate ocean topography determination which should significantly improve knowledge and understanding of the global ocean circulation. No scatterometer has flown on a satellite since SEASAT in 1978. The surface wind vector is an extremely important variable for oceanographic research. For a large number of ocean circulation studies, estimates of wind speed, which are obtainable from microwave radiometers and altimeters, are not very suitable as a proxy for the surface wind vector. With the scheduled launch of ERS-1 in 1991, its sequel ERS-2 to be launched three years later, and NSCAT on ADEOS, continuous decade-long scatterometer measurements may become a reality. Such platforms will become key observational tools for estimating the exchanges between the oceans and the atmosphere, such as the CO_2, which is of a major interest in the context of global change.

The estimate of the various components which intervene in the biological cycles at the ocean surface depends on our skill in measuring and interpreting satellite data measurements. These

include not only the wind, but also ocean color, surface temperature, and surface global radiation. The Coastal Zone Color Scanner (CZCS) data base is still being used for inferring the color of the ocean, and more elaborated quantities such as the phytoplankton pigment concentration. Some work has been done to assess the quality of the algorithm used to remove the atmospheric effects. A modification of the currently used algorithm to correct for aerosols effects is being considered. New ocean color sensors are planned for flight in the coming years (SEAWIFS, 1993; OCTS, 1995). Global sea-surface temperature are still monitored by NOAA polar orbiting satellites. Multi-channel techniques are now available for cloud detection, atmospheric corrections and observations of the El Nino phenomena. In the near future such a data set will be of major interest, in particular for studying teleconnections between El Nino events and climatic variability over land surfaces. Algorithms for estimating the surface global radiation at the ocean surface from geostationary satellites are also improving and an intercomparison is planned. These algorithms may integrate part of the ISCCP data base and results from atmospheric sounders.

2. Dynamics, geochemistry and climatology of the middle atmosphere

2.1 Atmospheric Chemistry.

The chemical composition of the atmosphere is greatly affected by the terrestrial and marine biosphere which, in turn, strongly affects their predominant populations. Many biogenic gases, including trace gases released at the surface, contribute to the greenhouse effect and initiate a complex chemistry both in the troposphere and in the stratosphere. Furthermore, natural cycles are perturbed by human activities. Large scale pollution occurs in regions where industrial activity is concentrated and also in the tropics where agricultural practices contribute significantly to surface emissions. Modeling of the chemical cycles in the atmosphere has become more sophisticated, but it suffers from various limitations, including our present knowledge of some chemical mechanisms and the uncertainties about the source and fate of the biogenic gases.

2.2 Stratospheric Aerosols

Aerosol and ozone data from the Stratospheric Aerosol and Gas Experiment (SAGE II) are now calculated. Analysis of the aerosol distribution has complemented the previous data set obtained from SAGE I, with a better precision regarding the seasonal, zonal and meridional variations. The decreasing impact of the El Chichon eruption can be fairly well monitored and the effects due to more recent eruptions are also well illustrated by the data. Study of the size spectrum of the aerosols will become feasible during the SAGE III with the addition of some appropriate channels.

2.3 Stratospheric Ozone

Ozone has a critical role in the Earth's ecological balance owing to its strong absorption of biologically damaging ultraviolet light. The discovery of the Antarctic ozone hole in 1985 has led to significant advances in our understanding of the physical and chemical processes affecting the ozone layer. The chlorofluorocarbon theory appears to be the preferred explanation for ozone depletion, as opposed to the so called dynamical theory. Based on the recognition that important chemical reactions may take place on cloud surfaces in Antarctica, the chlorofluorocarbon theory emphasizes the role of the polar stratospheric clouds. Their formation plays a double role. Reactions on the surface of cloud particles convert chlorine and bromine from unreactive to reactive forms and clouds contribute to net removal of nitric acid by precipitation. Loss of ozone in both the Antarctic and Arctic stratospheres proceeds by catalytic gas phase reactions involving both chlorine and bromine.

Observations of the Antarctic stratosphere composition have established that the chemistry of this region is highly unusual because of its extreme low temperatures. This leads to a greatly enhanced susceptibility to chlorine-catalyzed ozone depletion. Satellite data from the NASA experiments SAM II and SAGE I and II revealed that the polar stratospheric clouds are displaying changing abundances primarily due to temperature variations from year to year. The algorithm for

processing data from the Tiros Operational Vertical Sounder (TOVS) has been improved in order to estimate total ozone over the globe during both day and night. This algorithm also allows the detection of polar stratospheric clouds.

3. Geology and productivity of the land surface and the oceans

3.1 Geology

Remote sensing techniques are routinely used for mapping structural and lithologic information for various applications including mineral and energy exploration, hazard assessments, construction activities, waste disposal and environmental aspects of mining. Research emphasis is presently on high spectral and spatial resolution sensors, stereoscopic imaging from space, and high- resolution imaging microwave sensors.

Data from the Geological Remote Sensing Field Experiment (GRSFE) collected during the summer of 1989 in the Mojave desert are now being compiled for distribution on CD-ROM's. The data set includes measurements from the Airborne Visible Infrared Imaging Spectrometer (AVIRIS), the Thermal Infrared Multispectral Scanner (TIMS), and the Airborne Multifrequency Polarimetric SAR (AIRSAR), together with appropriate field and laboratory data for calibration and evaluation. This US experiment provides basic information for the development of improved space-borne observing systems during the next decade. As shown by French and local scientists, the combination of multispectral SPOT with panchromatic SPOT stereopairs proved to be valuable for geological reconnaissance, such as mapping of volcanic features in the Sierra Pena Blanca (Mexico) and mapping of zones liable to earth movement in Bolivia. New techniques on the use of Landsat Thematic Mapper (TM) and SPOT have been developed in the UK for mapping the change of surface mineral workings and for identification of alteration zones in mineral exploration. Improved methods for geologic structures analysis are being studied in France with an application to Mauretania. Methods for high mountain thematic mapping using satellite sensors have been developed in Austria and have been applied in joint projects on geological and erosion mapping in Nepal and Pakistan. Using Landsat, SPOT, and Large Format Camera (LFC) data, as well as for the mapping of the earthquake hazard in the Armenian earthquake belt. Images of the USSR's KFA-1000 cosmic photo camera, with a 5 meter resolution, are also used for geological mapping and assessment of earthquake prone areas, flood- prone areas and soil erosion in various regions of the Soviet Union. Methods for structural mapping of geological formations are being developed based on Synthetic Aperture Radar (SAR) of the USSR's COSMOS satellite.

3.2 Land Productivity

Various cooperative international projects using high-resolution satellite imagery, such as Landsat and SPOT, are dealing with agricultural planning, estimation of forest reserves, soil erosion and deforestation. These projects provide valuable information for optimizing the productivity of farming and also for studying natural and man-made impacts on desertification and other environmental conditions. More specifically, projects between NASA and Brazil for studying the Amazon rain forest and between European countries and local authorities in Central Africa and South-East Asia, consider the deforestation problems of the tropical forests. Studies for a satellite survey of high latitude forests are also being started in Canada, the United States and Europe.

3.3 Ocean Productivity

Satellite observations of ocean color, which is related to photosynthetic pigments in the phytoplankton, are used over various ocean areas to determine plankton pigment concentrations. In coastal areas Landsat imagery is applied to study suspended sediment properties and to monitor the distribution of spilled oil. Sea surface temperatures currently derived from AVHRR data are used to optimize the fish catches in the Pacific and in the South Atlantic. Landsat TM and AVHRR imagery processed in near real time were also used to monitor the algal concentrations in the Adriatic Sea and the North Sea during the summer seasons in 1989 and 1990.

II- APPLICATION ACTIVITIES

4. VAS

VAS data was used operationally by all of the National Weather Service (NWS) National Centers (NSSFC, NHC, NMC). Imagery of VAS-derived atmospheric stability and moisture parameters were used by NSSFC in defining outlooks and watch areas for severe weather. Imagery and a special VAS-derived Deep Layer Mean (steering current) analysis were used by NHC in the monitoring and forecasting of hurricanes (including Atlantic, Gulf of Mexico, and Caribbean Basin storms) which affect the United States. Imagery, satellite-derived wind fields, and moisture analyses were used by NMC in both the global forecast models and national forecasting programs.

5. GOES-Tap

GOES-Tap, a program enabling users to acquire high quality satellite imagery over telephone data circuits, continues to expand. Presently, there are approximately 350 primary users and over 500 secondary users of GOES-Tap data. These users consist primarily of NWS field forecast offices, but they also include the Federal Aviation Administration (FAA), other civilian agencies (both state and federal), DOD, private companies, universities, and the media. A significant number of high schools have also started receiving NOAA satellite images via GOES-Tap. GOES-Tap data consists of visible and infrared facsimile images from the GOES and NOAA satellites, Geostationary Meteorology Satellite (GMS) (Japanese), and Meteosat (European) spacecraft. During 1990, NOAA expanded its suite of available NOAA polar satellite products accessible to NWS field offices. In addition, high resolution polar imagery is now gridded and contains a machine readable identification code.

6. Satellite-based Fire Alarms

The National Geophysical Data Center (NGDC) of NESDIS, in partnership with the Department of Interior's National Park Service and Bureau of Land Management, has contracted with NASA to develop a prototype operational system for using the NOAA AVHRR for automated early detection of wildfires.

Wildfires caused great damage in 1988 and 1989. AVHRR thermal data can be used to detect fires day and night. The satellite data will be used to complement existing programs to help improve early detection of such fires. The techniques are scheduled to be tested during the 1990-91 fire seasons, for possible later operational implementation.

Besides providing a service to managers of public lands, these techniques have possible commercial applications and can be used to help monitor the global environment. For example the Food and Agriculture Organization of the United Nations is interested in implementing the technology when it becomes operational.

7. Volcano Hazards Alert Plan

The NOAA Volcano Hazards Implementation Plan became effective in 1989. This plan is designed to use NOAA satellite data and trajectory models to monitor volcanic ash clouds and forecast their movement in air space controlled by the FAA.

GOES and NOAA data are used to define the horizontal and vertical extent of ash, as well as its direction and speed of movement. Multispectral techniques are under development and evaluation to monitor ash plumes, which are semi-transparent to the visible or infrared spectrum. The

Alaskan Mt. Redoubt volcanic eruptions in late 1989 and 1990 have provided excellent data for improving these ash plume forecasts.

8. CoastWatch

In 1989, NOAA's CoastWatch support was upgraded to operational status. The Ocean Product Center (OPC) is a multi-line office NOAA facility supporting NOAA's operational, oceanographic, and marine meteorological needs. OPC serves as a focal point for delivering high-resolution satellite-derived sea surface temperature (SST) imagery, meteorological fields, and ocean feature information, electronically, in near real-time to NOAA facilities located in U.S. coastal areas. Research and development for the Great Lakes and Chesapeake Bay was initiated in 1990. An automated NOAA AVHRR Image Mapping System was completed and a prototype was used to map AVHRR sea surface temperatures automatically for use by the National Marine Fisheries Laboratory at Beaufort, North Carolina.

Scientists used government-developed software on a low-cost PC-based work station to extract environmental information to support Federal and State decisionmakers and researchers responsible for managing coastal living resources and ecosystems. CoastWatch is a project managed within NOAA's Coastal Ocean Program, which will eventually cover all marine areas within the U.S. exclusive ecological zone. In 1990, prototype CoastWatch activities were brought together into a comprehensive program focused on the south-eastern United States' coastal waters. The Interactive Marine Analysis and Forecast System and the NOAA Ocean Communications Network were components of the program.

The Center for Ocean Analysis and Prediction (COAP) was formed in 1989 to serve as a NOAA facility for developing and disseminating oceanographic products and services in support of NOAA's mission.

The National Ocean Service (NOS) operates three national ocean centers: the Navy/NOAA Joint Ice Center (JIC), OPC, and COAP. In the case of the JIC, satellite imagery represents the primary data source used to meet this nation's requirements for Arctic, Great Lakes and Antarctic analyses of sea/lake ice conditions, for both civil and military users.

9. Strategic Assessment Program

This program used NOAA and NASA satellite data to produce analyses which describe the physical and biological conditions within estuaries, adjacent coastal waters, and the continental shelf. Satellite images were acquired and analyzed to determine: the location and movement of estuarine plumes and shelf/slope fronts, the interactions and exchanges of water between estuaries and coastal oceans and the distribution and concentration of primary productivity zones. The analyses produced by this program are used by coastal managers to help monitor and assess the environment within which living marine resources must survive.

10. Precipitation

Improvements to the operational satellite rainfall estimation technique continued. A study of rain events, for which the precipitation had been inaccurately estimated, showed that large convective storm clusters are not as dependent on the environmental moisture amounts as are smaller storms. Further work studied the movement of convective systems that produce flash floods and showed most move towards the west or southwest. Long tropical moisture plumes that can be seen in GOES water vapor data are being examined as another diagnostic tool for heavy precipitation forecasting. A NASA developed, automated method for producing convective storm precipitation estimates, was tested. This technique will help in simultaneously monitoring the whole United States, instead of only one or two areas. This will insure that no potential heavy precipitation event would be missed, and will allow the meteorologists to concentrate on estimating precipitation and localizing forecasts. Heavy snowfall associated with mid-latitude storms was

also under study. These events are usually convective and appear to have many of the same developmental characteristics that are displayed by the summertime, flash-flood producing convective systems.

11. Aerosol Optical Thickness

In January, 1990, NESDIS made its experimental aerosol optical thickness product operational. The experimental production began in July, 1987. Contour charts and digital tapes have been archived at the National Climate Data Center (NCDC) since the summer of 1989. The aerosol optical thickness is derived from reflected solar radiation measured by channel 1 of AVHRR. The observed "cloud-free" radiances are compared with radiances computed from a radiative transfer model of the atmosphere/ocean system. The largest concentrations of aerosols are from dust blown off the deserts of Africa and Saudi Arabia and from haze emanating from the eastern United States and western tropical South America. The air over the oceans of the Southern Hemisphere appears to be much "cleaner" than over the Northern Hemisphere. This observation is consistent with the fact that there is more land surface area and industry in the latter.

12. The Climate and Global Change Program

Used at first to locate and track weather phenomena by providing images of clouds and storms, the operational satellites have developed into sophisticated remote sensing platforms for both operational and research purposes. While designed primarily for weather observations, the versatile instruments on board provide quantitative information on a number of climate variables. They are providing an unparalleled set of continuous environmental observations for researchers studying global climate change.

Examples of some of these observations include the following:

- Since 1969, global atmospheric soundings of temperature and moisture. Significant improvements in these soundings were obtained in 1979 with the introduction of TOVS.

- Since 1970, global sea surface temperature. High quality observations began in 1981 with the launch of a five-channel AVHRR.

- Since 1966, maps of snow cover showing, for example, that the summer snow cover over the Northern Hemisphere this past summer was the lowest of the entire 25 year satellite record.

- Since 1972, maps of sea ice cover on the oceans.

- Since 1982, weekly global maps of vegetation index, which is a measure of the vigor and density of green vegetation.

- Since 1974, quantitative estimates of the global distribution of Earth's albedo and emitted longwave radiation, which are the two major components of Earth's radiation budget.

- Since 1985, the global distribution of the total amount and vertical profile of atmospheric ozone.

Because they must meet the operational requirements for continuous data, the NOAA satellites have no gaps in the long-term monitoring record so critical for measuring global change.

While the NOAA satellite products can be applied to a number of problems in climate research, much remains to be done to produce research quality data sets. In particular, major reprocessing efforts are necessary from time to time. As improvements were made in the algorithms, the data

processing system was changed. Because the satellite's visible radiation sensors tend to degrade in orbit and there is no on-board calibration, the record of the changes can only be estimated from special analyses. NASA and NOAA are currently cooperating on a major effort to reprocess the entire long-term archive of three major instruments: the AVHRR, the TOVS and the GOES VISSR.

13. Ozone

A new physical processing procedure for determining total ozone from the TOVS polar sounders provided a potentially invaluable source of new data on the ozone field. Real-time operational TOVS information on the 1990 Antarctic ozone hole was made available to interested parties by NOAA. These data indicated that the 1990 ozone hole has developed from as early as mid-August into what appears to be the major ozone hole of the record low ozone amounts over the Arctic region which were recorded by TOVS. Whether or not the low 1990 springtime Arctic ozone values involve local chemical destruction is certain to be a subject of intense scientific debate. Low North and South polar ozone values contributed to an overall downward trend of global ozone since 1979 which, from the TOVS procedure, is estimated to be on the order of 4 percent.

14. Global Vegetation Index

The experimental Global Vegetation Index (GVI), product of NOAA, provided a weekly view of Earth's vegetation since May, 1982. The GVI is derived from daily data acquired by the AVHRR on board the NOAA polar-orbiting series of satellites with local orbit times in the early afternoon. A weekly composite is produced by using daily visible and near-IR data to screen the data of each map cell such that the "greenest" or most "cloud-free" data of each week is retained for each map cell. The Normalized Difference Vegetation Index (NDVI)is also computed for each map cell. It is based on the composite visible and near-IR data and is included in the weekly product that is available in several map projections. An experimental, quality controlled, bi-weekly NDVI product has been generated from the GVI data for 1985 through 1989 in a cooperative research effort with the United States Geological Survey (USGS) Earth Resources Observation System Data Center. The experimental NDVI product was distributed to several scientists for evaluation of its potential use in Global Climatic Models. Research efforts continue to improve the quality and use of the NDVI data and Global Circulation Models and as direct indicators of annual and regional variations in climatic conditions.

15. Snow-cover Observations

NESDIS continues to support its operational snow-cover mapping program. Weekly analyses, using GOES, Meteosat, and NOAA satellite data were prepared for the Northern Hemisphere. They show the boundary between snow-covered and clear ground. Techniques for blending microwave data (DMSP SSM/I) into the operational snow-cover mapping program are being evaluated. These weekly charts were provided to NWS for use in their global forecast models and stream- flow models and also to university researchers and private companies. These data, which were produced since 1966, comprise a valuable climatic monitoring resource.

16. Generic Cloud Algorithms

A multichannel algorithm for cloud detection is under development. The objectives are to provide a method for detecting clear pixels for remote sensing of surface parameters and to provide a means of estimating cloud amount and other cloud properties useful for diagnosis and construction of climate and weather prediction models. The technique uses all five channels of Global Area Coverage resolution AVHRR data. Cloud distributions from initial test results look realistic.

17. Sea Surface Temperature (SST) Measurements

Since 1981 measurements have been provided in real time on a global basis at a resolution of 4 kilometers using the multi-channel digital data (visible, reflective-IR and thermal-IR) obtained from the AVHRR instrument. A correction must be made for atmospheric attenuation by water vapor which is both highly variable and temperature dependent. Until 1990, a linear model was applied that assumed this correction was a constant multiplied by the radiative temperature difference. A non-linear model has been used since March, 1990 in which the constant became an explicit function of the scene temperature and the radiative temperature difference. Results show that the non-linear SSTs are more accurate than the linear SSTs, both under very dry atmospheric conditions when the radiative temperatures difference is quite small, and also under very moist conditions.

NOS is using satellite imagery to monitor SST as part of the 106-Mile Deepwater Municipal Sludge Dump Site project, which is being carried out jointly with the Environmental Protection Agency and the United States Coast Guard. SST imagery is used for the identification of surface water masses, as an aid in the interpretation of the tracks of drifters released at the site and for monitoring significant physical features such as the Gulf Stream and warm core rings.

18. Mesoscale and Severe Storm Research

NESDIS is conducting research on improving the use of satellite derived soundings for forecasting convection and severe thunderstorms. A technique has been developed that uses infrared satellite sounding measurements to probe the precursor conditions required for the formation of convective storms. These infrared measurements detect temperature and water vapor variations that define small-scale air mass characteristics and show more clearly that these characteristics and their inter-relationships are producers of intense thunderstorms.

19. Tropical Storm Research

Another NESDIS project is studying the forecasting and genesis of tropical cyclones and intensity using geostationary satellite data. Digital satellite data have been used to study the distribution, intensity, and time evolution of the deep convective cloudiness associated with this genesis process. Results show a convective maximum followed by 1 or 2 days of suppressed convective activity preceding the tropical storm stage.

20. Geosat

During the past 5 years the U.S. Navy altimeter satellite Geosat has provided nearly continuous measurements of global sea level, wind speed, and sea state. By arrangement with the U.S. Navy the NOAA Geosat project prepares and distributes raw data and products from this mission. Several hundred scientists in more than 40 institutions and countries receive geophysical data records on a regular basis. Although the Geosat satellite failed in January 1990, ending a long-standing flow of altimetric data, the interest in geophysical applications of the data continued to grow steadily. Launched in March 1985, Geosat substantially exceeded its expected 3-year life span. NGDC continued, along with the NESDIS National Oceanographic Data Center (NODC), to provide this community of users with publicly available Geosat data.

The Geosat project is a key element of the NOAA Climate and Global Change program, in particular of the NOS Sea Level portion. Satellite altimetry is the only way to obtain global and detailed determinations of sea level variations such as those associated with El Nino. In addition to providing data for oceanographic research, the Geosat mission has enabled the first operational monitoring of sea level over entire ocean basins. NOAA presently publishes sea level maps both of the Pacific and of the Indian Oceans in near-real time.

The Geosat altimeter is also being used to procure improved models of the geoid and of the gravity field of Earth's oceans. This information is fundamental to improving our understanding of Earth processes.

III- SPACE PROGRAMS

21. Geostationary Environmental Satellites

-Europe

Meteosat-4 (formerly MOP-1) continues to operate as a primary satellite by ESA on the behalf of Eumetsat. Meteosat-5 is scheduled for launch by Eumetsat in February, 1991. The studies of two different Meteosat Second Generation (MSG) configurations showed that the requirements of an imaging mission (with much better performance than the current MOP series) can be met by a satellite in the half Ariane-4 class. Plans are being made by the ESA Executive and Eumetsat Secretariat for the start of phase A in 1991.

-United States

After more than 8 years of service GOES-5 was de-activated on July 18, 1990. GOES-7 is the prime operational NOAA imaging meteorological satellite. The West WEFAX relay satellite GOES-6 is presently located at 135.8.

The Ford Aerospace and Communications Corporation is continuing the development and fabrication of the next generation GOES spacecraft, GOES I-M, and associated ground equipment. The GOES-I prototype imager instrument began its initial system integration testing in December 1989. GOES-I is scheduled to be launched in mid-1992.

Planning for a new generation of geostationary weather satellites, following GOES I-M, began in January 1989. A GOES requirements workshop was conducted by NOAA to collect information from the current users of geostationary satellite data. In August 1989, NASA started a Phase A study to assess technology feasibility, science requirements and the cost of this next proposed series of geostationary satellites.

The new DCS completed its first full year of service in 1990. The new system increased the number of remote data collection platforms which NOAA can support from 8,000 to 100,000 and provides a real-time broadcast of all data collected by the system. Rather than installing a costly GOES receiving system or using telephone lines for accessing data, users may install low-cost Ku band receivers and connect them to PCs to receive and process data. Using only one imaging satellite, the DCS has continued its international coverage (Eastern Atlantic to Western Pacific) using transponders from other non-imaging GOES.

-Japan

Following the launch of GMS-4 in September 1989, NASDA started the development of GMS-5 with the addition of a water vapor channel. GMS-5 is scheduled for a launch in mid-1993.

22. Polar-orbiting environmental satellites

-China

On September 3 1990, The People's Republic of China successfully launched its second experimental polar orbiting meteorological satellite Feng Yun-1B (FY-1B). FY-1B carries two 5-channel AVHRR instruments and revolves around the earth 14 times daily in a sun-synchronous orbit.

-France

The French satellite SPOT 2 was successfully launched at the end of January 1990. SPOT 2 is basically analogous to SPOT 1, except that it includes the Doris precision orbitography system, as well as SPOT 3, which is on schedule for a launch in 1993.

-Soviet Union

The polar satellite Meteor 3-3, launched on October 6, 1989, is operating and transmitting data. The ScaRaB radiometer designed to measure the earth radiation budget will be launched in fall 1991 on board a Meteor satellite.

-United States

NOAA-10 and 11 are the primary polar environmental satellites and are in good operational condition. NOAA-D, which was due for launch at the beginning of 1990, has been rescheduled for launch in May 1991. This spacecraft will carry the AVHRR, HIRS, SEM, MSU and the ARGOS Data Collection system. The next generation of polar satellites, NOAA-K/L/M, completed the Critical Design Review in August 1989. This new generation of polar satellites will carry improved instrumentation for all weather atmospheric soundings.

Pursuant to the Land Remote-Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT), operated both the Landsat 4 and 5 remote-sensing satellite systems for NOAA in 1989. During this time these systems acquired 37,000 images for domestic use and provided 320,000 images to foreign ground stations. In 1990 345,000 images were acquired by foreign ground stations, and 25,000 images were obtained for domestic use; the number of domestic images decreased because the spacecraft was showing signs of age. The National Space Council undertook a policy review of the Landsat program. The Council recommended a policy that would assure funds for the completion of Landsat 6 and the continued operations of Landsat 4 and 5. In May, 1989, this policy was approved. It also stated the commitment to continue Landsat-type data collections after Landsat 6. EOSAT continues to work on the design and development of Landsat 6, which is scheduled to be launched in 1991. In 1989, 15 foreign ground stations received Landsat data. The station in Pakistan became officially operational in 1989, and EOSAT negotiations with the Government of Ecuador for ground receiving station were also concluded.

-Japan

Of particular interest for global ocean studies is the Marine Observation Satellite MOS-1b, which was launched by Japan in February 1990 on a polar orbit, after its predecessor MOS-1a.

23. Future Platforms

23.1 United States

The launch of the Upper Atmospheric Research Satellite (UARS) is scheduled for August 1991. The evaluation of EOS proposals was finished in January 1989. The final selection of the instruments on board EOS-A will be made in October 1990. First EOS-A will fly in a sun-synchronous orbit with a two- day recurrent orbit. The launch is scheduled for 1998. The principal instruments will probably include the Moderate Resolution Imaging Spectrometer (MODIS) N and T (now entering into execution phase (C/D) development and implementation activities), the Advance Microwave Sounding Unit (AMSU) A and B, the Atmospheric Infrared Sounder (AIRS), and the ESA-developed radiometer called Multichannel Imaging Microwave Radiometer (MIMR). The next launch of an ocean color instrument, a NASA instrument called SEAWIFS, is scheduled for 1993.

23.2 Europe

The ERS-1, which was due for launch in September 1990, is now scheduled for April 1991. The package includes the altimeter, the infrared and microwave sounder ATSR/IR and M operating in bands 1.6, 3.7, 11 and 12 μm and 23.8 and 56.5 Ghz, respectively, the scatterometer in band C, the SAR in image and wave modes, and precision orbitography systems. After launch, the initial phase will include extensive calibration and validation testing centered around Norwegian coastal areas. Preparatory work for this is well advanced. The design of the Aristoteles mission has been completed. Aristoteles will include accelerometers for determining local gradients of the gravity fields and a magnetometer. This will allow measurement of the Earth's gravity field with a mean error of 5 mgals on a resolution scale of 100 by 100 km^2 all over the Earth.

23.3 Soviet Union

Within the next two years, the USSR plans to launch the PRIRODA equipment package for remote sensing of the Earth and for environmental research. The package will be accomodated on one of the modules of the MIR orbital station and will include the visible and infrared spectrometers MOZ-OBZOR, MSU-SK, MSU-E, a television camera, the microwave radiometric system IKAR, the infrared spectroradiometric system Istok-1, a dual-frequency SAR, and the Ozon-M and Soviet-French Alissa equipment for measuring ozone profile and cloud heights, respectively.

23.4 France

The French-US Topex/Poseidon altimetric mission is scheduled for launch in June 1992 in phase with the WOCE intensive field experiments. BEST, a GEWEX dedicated mission currently under study, is considered for the late 90's. As a contribution to IGBP, a phase A study of a new project called Globsat has been initiated by the end of 1989. The two main objectives of Globsat are the understanding of the biogeochemical cycles and their impacts on the atmospheric chemical composition and on the marine and terrestrial ecosystem, as well as the monitoring of greenhouse gases in the atmosphere. Globsat facility instruments include an infrared spectrometer, a stellar occultation spectrometer (GOMOS), a visible infrared imager, the ScaRab instrument and a radiometer for measuring the colour of the ocean. It is possible that launching of this polar mission will be considered for 1996.

23.5 Japan

The National Space Development Agency of Japan (NASDA) is developing and planning Earth observation satellite programs for exploring natural resources (JERS-1), for investigating global change (ADEOS), for measuring precipitations in the tropics (TRMM), and for carrying out

comprehensive observations in the style of EOS-A (JPOP). JERS-1, whose launch is scheduled in early 1992, includes the Synthetic Aperture Radar (SAR) for land surface topography and the Short-Wave Infrared Radiometer (SWIR) for measuring reflected radiances in the visible and short wave infrared bands. ADEOS instruments include the Ocean Color and Temperature Scanner (OCTS) for measuring the carbon cycle, supplemented by the NASA scatterometer NSCAT and the French instrument (Polder) for measuring Polarisation and Directionality of the Earth's Reflectances. In addition to the above facilities ADEOS also includes the spectrometers TOMS and ILAS as well as the interferometer IMG documenting atmospheric profiles. The launch of the ADEOS platform on a sun-synchronous orbit is scheduled for 1995. TRMM, which is a joint program involving NASDA, NASA and CRLJ, is scheduled for launch in a non-synchronous orbit by 1996. The TRMM instrumentation includes a precipitation radar, in addition to AVHRR, SSM/I and ESMR. The Japanese Polar Orbiting Platform (JPOP) is NASDA's successor to ADEOS. Whether it will effectively fly on a near polar-orbiting sun-synchronous or a low-inclination non-sun-synchronous orbit is a major issue under discussion, related to the GEWEX observational requirements. The launch is scheduled in early 1998.

IV -INTERNATIONAL COMMITTEE ACTIVITIES

24. World Meteorological Organization Panel of Experts on Satellites

In November 1989, NOAA participated in the WMO Eighth Session of its Executive Council Panel of Experts on Satellites (ECSAT). ECSAT is an advisory panel which reviews WMO satellite activities and makes recommendations pertaining to coordination of meteorological satellite programs of member states and plans to ensure continuity of observational capabilities from space.

The Panel reaffirmed the practice of free and open exchange of data for operational meteorology and climate research. The Panel encouraged satellite operators to ensure the compatibility of national satellite systems, in order to assure continuity of coverage. The Panel recommended that the definition of operational system continuity be expanded to include maintenance. The Panel also recommended that national and international space research organizations be encouraged to accept requirements from the meteorological community stated through WMO and to give these requirements priority.

The WMO Commission for Marine Meteorology (CMM), jointly with the Intergovernmental Oceanographic Commission (IOC), re-established the Working Group on Technical Problems to prepare an annual report on the development of the main remote sensing programs relevant to marine meteorology and physical oceanography. The group consists of an *ad hoc* group on oceanic satellites and remote sensing, presently chaired by NOAA/NESDIS with members from the United Kingdom, The Netherlands, France, and the U.S.S.R.

25. International Forum on Earth Observations Using Space Station Elements (IFEOS)

In April 1989, IFEOS met in Ottawa, Canada. IFEOS was created to examine technical and operational aspects of using the polar platforms of the International Space Station for Earth observations. As a result of a joint NOAA/NASA resolution, IFEOS was disbanded by unanimous consent. The rationale for dissolution of the group was as follows: 1) IFEOS had been successful in achieving its' goals as evident in the Space Station partners' efforts to establish a global Earth observation system based on the polar platforms of the International Space Station and 2) other international groups, primarily the Committee on Earth Observation Satellites (CEOS), can effectively carry on the work of international coordination of Earth observation activities of member agencies and countries.

26. Coordination of Geostationary Meteorological Satellites (CGMS)

In December 1990, the CGMS group, which serves as an informal technical forum through which independent national meteorological programs can be coordinated in order to achieve common meteorological mission objectives, met in Tashkent, U.S.S.R. The CGMS participants, including the European Meteorological Satellite Program (EUMETSAT), India, Japan, the United States, the U.S.S.R., the Peoples Republic of China, and WMO, continued their work in allocating radio frequencies for the data collection system and in standardizing formats for WEFAX computer codes.

27. Committee on Earth Observations Satellites (CEOS)

CEOS, formed in 1984 as an outgrowth of the international Economic Summit of Industrialized Nations, serves as a coordinating forum for the overall Earth observations space community. At its April 1989 meeting, the CEOS stressed the coordinated planning required for Polar Platforms and future missions.

For the benefit of members and the international user community, the CEOS Working Group on Data (WGD) defines areas for increased coordination and standardization of data management for space-borne Earth observations. Its data product subgroup coordinates standardization of user product formats. Member countries have agreed to incorporate endorsed sensor formats into ongoing data management planning. The Catalog Subgroup, which is chaired by NESDIS, is working on developing and promoting an approach for achieving an inter-operable international catalog system. WMO is considering a proposal by Japan on a worldwide Network for Global Environmental Monitoring from Space. Other projects include a data dictionary, networks, and distribution media coordination. The CEOS Working Group on sensor calibration and performance validation, which is chaired by the European Space Agency, fosters technical coordination and cooperation between space and ground segments in terms of mission parameters and sensor calibration and performance validation.

28. International Polar Orbiting Meteorological Satellite Group (IPOMS)

The 1984 Economic Summit of Industrialized Nations endorsed the creation of IPOMS to explore mechanisms for increased international cooperation in support of polar-orbiting meteorological satellites and to ensure continuity of these satellites.

In 1989, letters of intent concerning potential contributions to the next series of polar-orbiters were received from all IPOMS members. Notable is the European plan to provide instruments and spacecraft for morning polar orbit and instruments for afternoon polar orbit. At its September 1990 meeting in Venice, Italy, contributors were encouraged to pursue formal agreement and to plan for data access and continuity.

29. World Administrative Radio Conference

The Consultative Committee International Radio (CCIR), part of the International Telecommunication Union (ITU), performs technical studies that are used in the deliberations and decisions of the ITU. CCIR Study Group 4 (SG 4) has the responsibility for studies pertaining to Fixed Satellite Service in which NTIA (National Telecommunications and Information Agency) participates. Our participation included submission of technical material pertaining to the sidelobe characteristics of antennas used for Earth stations, participation in the final meeting of CCIR SG 4 for the 1986-1990 study period and recent studies on implementing Integrated Services Digital Networks over satellite links.

30. Pan-Pacific Education and Communication Experiment by Satellite.

The PEACESAT program was founded by the University of Hawaii in 1971 and provided a satellite telecommunication network for exchange of social, environmental, health and educational information among the countries of the Pacific Basin region using NASA's ATS-1 satellite. In 1985 its fuel was exhausted, and the satellite drifted away from a location useful for communications throughout the Pacific Basin.

In December NTIA was authorized to assist the University of Hawaii in the re-establishment of PEACESAT service. NTIA's responsibilities have included supporting PEACESAT activities at the University of Hawaii, providing technical consultation there and to the PEACESAT Users' Group, funding a study of PEACESAT satellite options and obtaining satellite capacity for use by the PEACESAT system.

Consultation has been provided on the suitability of using NOAA GOES-3 satellite and engineering support in the design of the Users'-Terminal Earth station, selection of a contractor to build the Earth stations and the purchase and installation of the stations. NTIA activities connected with PEACESAT in 1990 focused on developing the telecommunications required to re-establish PEACESAT satellite communications. The use of NOAA's GOES-3 satellite for the period 1990-1994 was obtained. Agreement was also reached with NASA to operate the satellite from Hawaii. Low-cost user Earth terminals have been developed and tested for use with the satellite.

CHAPTER TWO

SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS, SMALL BODIES OF THE SOLAR SYSTEM

1. The Terrestrial Planets

a. Venus

In February 1990, the Galileo spacecraft made a successful flyby of Venus. Most of the data obtained during the flyby were recorded for later playback in November 1990; upon the spacecraft's approach to Earth. This delay was a consequence of the heat shielding precautions taken for Galileo's venus encounter, which required the high gain antenna to remain furled.

Three images recorded at effective wavelengths of 4200 and 9900 Å have already been returned from the solid state imaging camera. The short wavelength images reproduce the appearance of the planet that is familiar from previous Earth-based and spacecraft observations. The 9900 Å image shows new features in the clouds, presumably at lower altitudes in the planets atmosphere. When the complete data set is returned in November, it will be possible to look for correlations in the appearance of the planet at two wavelengths and to investigate additional relationships with the spectral mapping images produced at still longer wavelengths by the NIMS experiment.

The Magellan spacecraft was successfully put into orbit around Venus in August. Some preliminary radar images of the planet's surface were obtained almost immediately, but then communication with the spacecraft was interrupted. These first results indicate that the planned resolution of 100 meters had been achieved. Meanwhile, the spacecraft is again working normally.

The study of results of earlier missions, especially Venera 15/16 radar survey, was in progress. These studies have shown that Venus, often called the sister planet of Earth, is quite different from Earth with respect to style and intensity of igneous and tectonic activity.

b. Mars

The processing and analyzing of data from the Phobos-2 spacecraft has been continued. New results were obtained for the equatorial zone of Mars. IR mapping spectrometry has shown that the degree of hydration of Martian soil varies laterally. Detailed altitude maps of several areas have been produced. Scanning IR radiometry has revealed variations of thermal properties of surface material. Several photometrically distinct groups have been distinguished for Martian regolith. Gamma spectroscopy demonstrated the essentially mafic composition of the surface material, which has minor variations in the lateral material.

The study of the interaction of Mars with the solar wind led to the conclusion that it mainly involves an extended Martian ionosphere/exosphere. New plasma boundaries were found which characterize this type of planet/solarwind interaction. Studies indicate the possible presence of a weak Martian magnetic field.

The next mission to Mars, the Mars observer spacecraft, is scheduled for launch in 1992.

c. Phobos

Study of Phobos concentrated on the analysis of data obtained by the Phobos- 2 space probe. These observations have already significantly changed our knowledge of Phobos. Based on TV imagery the figure of Phobos has been determined with higher accuracy. Radiotracking has refined significantly the value of Phobos' mass. The estimation of Phobos' bulk density gives an unexpectedly low value of (1.95 ± 0.1) g/cm^3. Spectroscopic observations over a wide range of wavelengths have shown that, contrary to widely accepted ideas, the surface material of Phobos

differs from that of typical low-grade carbonaceous chondrites. In particular, it is much less hydrated than the material of CI and CM meteorites. Spectroscopic signatures and thermal properties of Phobos vary noticeably from place to place.

The results of TV observations added local precision to the known surface maps of the surface of this body and plasma measurements indicated variable dust distributions at and near the orbit of Phobos.

d. The Moon

The Galileo spacecraft will make observations of the Moon (in the course of its trajectory to Jupiter). These opportunities will present themselves during the two Earth encounters in December 1990 and December 1992.

2. The Outer Planets

a. Jupiter

The Galileo spacecraft was successfully launched in October 1989. It completed its scheduled flyby of Venus in February, 1990 and will have the first of its two Earth-Moon encounters in December 1990. All systems are working normally. The Jupiter encounter is planned for December 1995.

b. Saturn

In October 1989 the US Congress authorized financing for the NASA-ESA Cassini-Huygens mission. The payload for this orbiter-probe mission is presently being selected and launch is scheduled for 1996.

c. Neptune

Data analysis is still continuing from the highly successful encounter with the planet by the Voyager 2 spacecraft in August 1989. Perhaps the single most important new result since last year's report is the detection of active 'geysers' on the surface of Triton: vertical jets of material rising some 8km into the tenuous atmosphere from the 37°K surface. The physics and chemistry of this phenomenon are subjects of active study.

3. Small Bodies in the Solar System

a. Asteroids

The Galileo spacecraft has opportunities for two asteroid encounters in the course of its trajectory to Jupiter: Gaspra in 1991 and Ida in 1993. Both the Cassini-Huygens and the Craf spacecraft will also have close flybys of asteroids en route to their principle targets.

b. Comets

The US Congress authorized NASA to begin implementing the Craf mission at the same time as it approved the new start for Cassini-Huygens. The payload for this spacecraft, whose rendezvous target is comet Kopff in the year 2000, has already been selected. Launch is scheduled for April 1995.

Based on a continued investigation of the data from the VEGA and Giotto spacecraft, ground-based astronomical observations, and related laboratory experiments, modelling of cometary nuclei and their activity has made good progress in preparing for future cometary missions.

c. Dust

The dust experiment onboard Galileo made its first successful measurements during its first solar orbit between 0.7 - 1.2 AU.

Exposition experiments for dust (and orbital debris) were carried out by LDEF (5 year exposition) and by the MIR station. The material is now under laboratory investigation.

First results from the dust experiment onboard MUSES (launch January 1990) were obtained for dust distribution in the Earth-Moon system.

CHAPTER THREE

SPACE STUDIES OF THE ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

1. The Earth's Middle Atmosphere

During the last two years, research on the Earth's middle atmosphere has progressed in two directions. One aspect has been intensified studies inside the middle atmosphere using both experimental and theoretical methods. The other important aspect has been investigations of coupling mechanisms between the middle atmosphere and the atmosphere above and below it; both on local and global scales. Examples of both directions will be mentioned below.

It appears that fine structure layers are much more frequent in the middle atmosphere than anticipated some years ago. A special session on this subject was held during the last COSPAR meeting in The Hague. Observational evidence for such layers, e.g. in the upper mesosphere sodium layer, was presented together with theoretical studies of creation mechanisms such as instabilities caused by gravity wave breaking.

The international project DYANA (Dynamics Adapted Network for the Atmosphere) was accepted as the first STEP project. This project was carried out in early 1990 at various places on the globe to study middle atmosphere dynamics up to about 100km. The main emphasis of this campaign was on global aspects of planetary waves, gravity waves and turbulence. Numerous ground-based, balloon and rocket borne experiments were involved and their data are currently being evaluated.

Considerable effort was devoted to understanding the coupling mechanisms between the middle atmosphere and the layers above and below, as well as to the relation between solar and atmospheric activity.

The role of dynamical processes (e.g. tides, gravity waves and turbulence) and chemistry was studied. The investigation of the correlation between the 11-year solar cycle and the thermal and dynamical properties of the atmosphere, discovered for the middle atmosphere in 1988, was intensified and expanded to regions above and below.

The evaluation of the results from Middle Atmosphere Cooperation (MAC) has continued. In particular the two campaigns MAC/SINE and MAC/EPSILON have proved successfull. A special issue describing the results is currently in press.

2. The Earth's Upper Atmosphere and Ionosphere

During the two year period under review the national and international space research efforts carried out within the areas of the thermosphere and ionosphere have been limited by the relatively small number of dedicated rocket and satellite launches which have occurred.

The last major spacecraft dedicated to research in this field was the San Marcos spacecraft launched in March 1988. The preliminary results from this mission were presented in a special session on 'Equatorial Aeronomy'at the 1990 COSPAR meeting in The Hague. It has provided observational data on electric fields, the neutral upper atmosphere and the ionosphere, as well as on precipitation of energetic particles and solar ionising fluxes.

Individual instruments have continued to be flown on a number of spacecraft dedicated to other primary purposes. Particular examples are the Space Environment Monitors on the USA NOAA/TIROS Spacecraft which define and routinely monitor the energetic particle fluxes incident on the upper atmosphere. Future NOAA/TIROS Spacecraft will also carry the Remote Atmospheric and Ionospheric Detection System (RAIDS), which will monitor the density

distribution of thermospheric and ionospheric species by means of limb scanning from a high-inclination orbit near 800 km altitude. The US DMSP Spacecraft will also carry instruments which measure ion drifts and field aligned currents, in addition to the energetic particle precipitation incident on the upper atmosphere. Using data from these and other orbital instruments (including data from instruments on some spacecraft whose primary purpose is magnetospheric or plasma physics research), in combination with data from networks of ground-based instruments, it has been possible to carry out a series of cooperative programs for studying the large-scale response of the thermosphere and ionosphere to varying solar and geomagnetic activity conditions.

The primary measurements of solar and magnetospheric energy inputs to the thermosphere and ionosphere can also be used to define the inputs to global numerical models. Such models can now provide near real-time computations of the overall qualitative response of the thermosphere and ionosphere. There remains the major problem of obtaining indices related to solar and geomagnetic activity, which faithfully reproduce the highly detailed and time-dependent patterns of auroral precipitation and plasma convection. There are no space missions planned for investigating one of the critical outstanding issues: the global measurement of mesospheric, thermospheric and ionospheric dynamics. These inter-related motions control many aspects of the chemical and energetic behaviour of the upper atmosphere and ionosphere. The current state of knowledge is dependent on a highly fragmentory data base and numerical models. Due to the shortage of real observational data these numerical models have unfortunately never been validated.

The global electric circuit is largely driven by the external magnetospheric convective field at high latitudes and by the global E-region dynamo with an internal source, mainly thunderstorm generated fields in the lower atmosphere. Investigations of the global electric circuit have been re-activated as a result of the discovery of occassional but unexpectedly large middle-atmosphere electric fields. Combined studies using rockets and ground based radars and lidars are planned in the near future to observe the behaviour of the high-latitude summer mesopause and lower thermosphere in order to study the combined chemical, dynamical and electro-dynamical behaviour during Polar Mesospheric Cloud periods, and during Noctilucent Cloud events.

A considerable amount of progress in thermospheric and ionospheric studies is now coming from ground based optical and radar measurements. This empirical work is strongly supported by major research programs using sophisticated numerical models of the coupled atmosphere-ionosphere regions. Further valuable information on the magnetospheric inputs of energy and momentum comes from monitors in meteorological program spacecraft in low earth orbits. These measure energetic processes, auroral emissions, electric fields/ion drifts and field aligned currents. Unfortunately, none of the plans of the major space agencies include significant resources for appropriate direct and remote sensing observations of the thermosphere and ionosphere, using a coordinated package of synergetic instruments prior to the ESA/NASA polar platforms in the late 1990's. Some valuable measurements of the lower thermosphere will be made in the 1991-1993 period from NASA's Upper Atmosphere Research Satellite (UARS).

The CRIT 11, PEGSAT and the first series of CRRES chemical release experiments have been successfully completed. A second series of CRRES chemical release experiments will occur during early - mid 1991. Injection experiments such as ARCS, Spear and NEED have occurred with further experiments in these series being planned for the future, including wave injection experiments combined with ground based ionospheric heating.

3. Planetary Atmospheres and Aeronomy

The Galileo mission to Jupiter is under way and the probe is functioning well. The Cassini-Hugyens probe has been approved by NASA and ESA. The Giotto probe has been checked out by ESA and a decision has been taken to prepare for an encounter with the comet Grig-Skellerup.

The COSPAR Task Group on the *Venus International Reference Atmosphere (VIRA)* met during the XXVIII Meeting of COSPAR in The Hague, the Netherlands primarily to discuss the necessity of updating the VIRA document which was published as No. 11, Vol. 5 of *Advances in Space Research* in 1985. Since then it has become a much consulted reference work on the Venus atmosphere and ionosphere, but has been out of print for some time. It was decided that the publication of a completely updated VIRA document must await not only new data to be provided by the low-periapsis phase of the Pioneer Venus mission, which will occur in 1992, but also contributions of radio occultation measurements from the Magellan mission. This makes it impractical to begin the editorial process before 1994. The chapter on the Venus ionosphere, for which much new material has been collected since the original publication, will be updated by a separate publication in *Advances in Space Research.*

4. Earth Reference Atmospheres

Compilation of the new *COSPAR International Reference Atmosphere (CIRA)* is underway. The new expanded CIRA uses the international reference atmospheres adopted by COSPAR in 1961, 1965 and 1972. The new CIRA will be divided into three volumes: Volume 1 - The Thermosphere, Volume 2 -The Middle Atmosphere models, Volume 3 - Trace Species. Volume 1, which includes a semi-empirical thermosphere model and new theoretical and empirical models, has been published by Pergamon Press. This first Volume was published in Vol. 6, Nos. 5-6 *Advances in Space Research* under the title "CIRA. 1986 Part 1 - Thermosphere Models" (Rees, D. Editor). The second volume of CIRA (Labizke, R, Rees, D. and Barnett, J., Editors) has been submitted to the Pergamon Press for publication. The middle atmosphere volume of CIRA includes satellite data whereas the earlier versions used for *in situ* and ground based measurements. The two hemispheres are treated separately, and values are provided at closer spacing than before. Tables are provided of zonal mean temperature, geopotential height, zonal wind and pressure as functions of latitude. Mean longitudinal variations in the form of the amplitude and phase of planetary waves 1 and 2 are included both for the stratospheric and for the mesospheric. Other atmospheric variations including tides, turbulences and interannual variability are also treated. Comparisons are made between selected data sets and the new reference atmosphere. For the first time, systematic variation of the zonal mean ozone is included. These cover ozone as a function of latitude and season in both the stratosphere and mesosphere, using combined data from 6 satellite experiments.

In 1990, COSPAR established the Task Group on International Reference Atmospheres of Trace Species in order to compile Volume 3 of CIRA. Reference models are being developed of O_3, N_2O, HNO_3, N_2O, CH_4, CO_2, CFC's and aerosols in the middle atmosphere, and NO and O in the lower thermosphere. In accord with a proposal of the MAP Steering Committee of SCOSTEP (of ICSU) an earlier version of these reference models was submitted for publication in a MAP Handbook for distribution to and feedback from the international scientific community prior to publication of Volume 3 of CIRA. The models may be used as a common means of comparison of measurements, as a common reference model for comparison with theoretical studies and as a common input where measurements are dependent upon "first guess". An international workshop was held on trace species at the 1990 COSPAR meeting, where new information on a number of trace species (including H_2O, O_3, O, H, and NO_2) was presented.

The International Reference Atmosphere (IRI-90) Handbook prepared by D. Bilitza will be released by the National Space Science Data Center (NSSDC) before the end of 1990. This is the outcome of a joint URSI/COSPAR Task Group on IRI.

According to the terms of reference of IRI, it will contain six chapters. They will be related to : the general IRI projects, an ion drift model, a model of ion composition, a model of the cluster and negative ions repartition, the plasma temperatures anisostropies and the relations of IRI with the measurements of electron content. The revised computer code will also be described using the experience gained recently.

At the last IRI meeting at the Hague, emphasis was put on needs for extensive and consistent data bases and on the global and regional mapping of the necessary parameters. Developments towards the description of auroral conditions and solar activity effects are also expected.

Two future meetings are already scheduled:

- a workshop in Athens (Greece) on "Advances in Global/ Regional Description of Ionospheric Parameters" in September or October 1991.
- a symposium on "IRI: Verification and Future Development" at Washington DC (USA) during the COSPAR XXIX Plenary Meeting, 1992.

As usual, the activity and the achievements of IRI are the results of a very active and broad international cooperation.

CHAPTER FOUR

SPACE PLASMAS IN THE SOLAR SYSTEM

The most tenuous parts of the solar system are in the plasma state, the upper levels of the Earth's atmosphere, the outer corona of the Sun, the solar wind, the ionised atmosphere of each of the planets, the magnetospheres of Jupiter and Saturn, and the extended plasma environments of comets. The bulk of our knowledge of the physics of plasmas in space comes from measurements made *in situ* by space probes.

Substantial additional information has come from balloons, rocket probes and ground based facilities such as radars. All the planets of the solar system as far out as Neptune have now been visited by spacecraft. Orbiters have studied the plasma environment of Mars and Venus. During the last year an orbiter, (along with a probe) was launched to Jupiter. For the first time the Earth was used for a gravity assist manoeuvre to enable interplanetary spacecraft to change orbit (the GEM encounter in early July 1990). Plans were also announced for a joint American-European Saturn orbiter and Titan probe to be launched later in the decade. Both will add substantially to our understanding of the plasma environment of the giant planets. As space vehicles like PIONEERs 10/11 and VOYAGERs 1/2 probe further from the Sun, we await the first indication of the heliopause, the boundary of the heliosphere, which marks the limit of the Sun's direct influence in space.

The launch of the Galileo, ACTIV, CRRES, spacecraft and Earth fly-bys of GEM and Galileo have made this year an important one for space plasma physics.

The ESA Giotto spacecraft (which completed a very successful encounter with the comet Halley in the spring of 1986) was brought back to life in the spring of this year. Although it sustained damage in its close passage by the Halley nucleus, the spacecraft magnetometer is working, as are various charged particle instruments. The spacecraft is now re-targetted to intercept comet Grigg-Skellerup. It became the first spacecraft to use an Earth gravitational assist manoeuvre in July during the re-targetting process. The spacecraft mission is now known by the acronym "GEM" (Giotto Extended Mission). Giotto only narrowly gained its title to first Earth gravity assisted mission. In December 1990 the Galileo spacecraft will make a close Earth flyby to gain energy. This energy is necessary in order to send such a large orbiter and probe on its journey to the Jupiter system. Galileos'fly-by of Venus earlier in the year produced little interesting information on the Venus plasma environment. There are chances for better luck at Earth, where the encounter trajectory takes the spacecraft on a long pass more or less up the axis of the Earth's magnetotail. This will be a unique view of the Earth's magnetosphere, and one hopes for some substorm activity during the encounter.

The analysis of data from spacecraft missions highlighted in recent years was continued. The results from the field and plasma instruments on the Phobos spacecraft have revitalized the arguments concerning the nature of the Mars-solar wind interaction. The results from the Voyager encounter with the Neptune system have inaugurated work which, due to the highly offset dipole of the internal planetary field and its inclination to the rotation axis, make it one of the most unexpected magnetospheres yet studied. The Japanese Akebono (EXOS D) spacecraft is providing new material concerning the Earth's magnetosphere.

The Phobos spacecraft was equipped with magnetometers, plasma wave detectors, and charged particle detectors for studying the martian plasma environment. The most critical question remaining concerning Mars, namely whether there is an internal magnetic field, remains a matter of intense controversy. There is more consensus that the solar wind-Mars interaction is little affected by any internal field.

The precise mechanisms whereby the induced magnetosphere forms remain to be worked out. The Phobos results show a clear boundary between the solar wind environment and the planetary

environment in the form of a fairly sharp spatial compositional boundary. Little magnetic signature is seen here although it is seen with all other planets. The latter circular orbits, which cross the magnetotail at about 6000 km distance, detect a field whose orientation depends on the upstream solar wind field direction rather than indicating any planetary related component. Large fluxes of planetary ions have been detected flowing out of the Mars magnetotail. The fluxes are large enough to have an impact on the planetary oxygen budget if extended over the age of the solar system. Because of spacecraft failure prior to encounter with the eponymous moon, little new in scientific information about Phobos has emerged from the mission. Various plasma and field instrument teams have, however, presented evidence of the presence of a Phobos dust--plasma interaction associated with a dust ring extending around the entire Phobos orbit.

The Phobos mission marked the start of a Soviet programme of Mars exploration which will continue to the end of the next century. The next major mission is planned for launch in 1994.

The plans for the major international ISTP (International Solar Terrestrial Physics) programme have gone forward this year. Two of the spacecraft of the planned flotilla to investigate all aspects of the coupling between the Sun and the terrestrial ionised atmosphere has been launched. The Japanese Akebono spacecraft, which was launched last year, has continued providing data. New images of the Earth's aurora have been obtained along with a variety of other measurements of auroral related phenomena. The CRRES (Combined Radiation and Release Experiment) spacecraft was successfully launched from the Kennedy Space Center, USA in August. It will investigate the radiation belts of the Earth in the first dedicated major study since the late sixties and will also perform a series of controlled release experiments in both low and high altitude. The latter component of the mission comes under the heading of active experimentation in space and has been an increasing part of COSPAR Commission D's activities in recent years. The Soviet Activny spacecraft is to be launched in September. Coordinated study using Akebono, Activny and the US Dynamics Explorer spacecraft is planned early in the new year.

Planning continues for the ESA/NASA STEP space programme, made up of two separate missions, known as Soho and Cluster. The spacecraft are linked in more than an engineering or programmatic sense. The expectation is that the coordinated observation programmes in solar and solar- terrestrial physics will give rise to cross-fertilization between these fields and joint advances in understanding plasma-physical phenomena common to both the solar atmosphere and the Earth's magnetosphere and near-Earth interplanetary space (Geospace). Plans are also progressing for the coordination of the Cluster mission with a series of Soviet spacecraft known as Regata following a useful joint workshop attended by scientists from both eastern and western Europe. Cluster is a four-spacecraft mission designed to study in detail processes like magnetic reconnection, hydromagnetic waves and turbulence which occur in other solar, planetary and astrophysical contexts. These can be studied *in situ* in a manner impossible in other situations. The boundary regions between the magnetospheric and solar wind plasmas are the site of a variety of anomalous plasma phenomena which are not well understood. New understanding of fundamental physical phenomena will result from the first use of multipoint measurements in the high altitude magnetosphere.

During the nineties, space agencies in the United States and Japan, ESA in Western Europe and Intercosmos in Eastern Europe are putting together a large multi-spacecraft programme to investigate plasma processes in the near-Earth space in the next decade. The major Japanese contribution, Geotail, will explore the magnetotail of the Earth's magnetosphere. NASA spacecraft will monitor conditions upstream of the system in the solar wind and the distant polar magnetosphere. A Soviet spacecraft, the first of the Regata series, will cover the near-Earth tail. This phase will be followed by the ESA-led Cluster mission, wherein four spacecraft will fly in close formation to study field and plasma microstructure in the magnetosphere in coordination with a parallel Soviet spacecraft programme as mentioned above.

Soviet scientists are leading an Intercosmos multi-spacecraft programme, Interball, which is also directed at the study of magnetospheric plasma processes. This programme, which is in some

respects a development of the recent Dynamics Explorer and Viking projects, will use pairs of spacecraft in low and high orbit respectively to study the interrelationship of ionospheric and magnetospheric processes.

Heliospheric work is starting a new period of activity. The ESA/NASA Ulysses spacecraft was launched on October 6th 1990. The Ulysses mission will explore the interplanetary medium, the solar wind, the solar magnetic field and the access of cosmic rays significantly out of the ecliptic plane. The spacecraft will fly to Jupiter first where a gravity assist manoeuvre will send it out of the ecliptic plane to explore the distant solar environment over the poles of the Sun. Until Ulysses is launched our direct knowledge of the extended solar environment, the solar wind, is restricted to the ecliptic plane. Ulysses will introduce the third dimension, which at present can only be studied by rather indirect means such as by examining interplanetary radio scintillations.

No spacecraft has yet reached the edge of the solar influence in the interstellar medium, the hypothetical boundary known as the heliopause, but Pioneer spacecraft and now the two Voyager spacecraft are heading out of the solar system and must eventually reach the interstellar medium beyond the heliopause. The most distant spacecraft is Pioneer 10, which is 48 AU distant from the Sun and is at a heliospheric latitude of 30°. Pioneer 11 and the Voyager complete the set of outer heliospheric probes.

The recent analysis of radio emissions detected by the Space Voyager spacecraft seem to indicate that the heliopause is no more than 100 AU from the Sun. A 3 kHz interplanetary radio frequency emission monitored on the spacecraft is increasing in frequency; one explanation of this is that the radio emissions are trapped between the heliopause and structures in the solar wind moving outwards from the Sun at about 400 kms^{-1}. By interpreting the frequency change as due to a Fermi acceleration process one may estimate the heliopause distance.

Ulysses will further advance our knowledge of cosmic rays. There have been important new results concerning cosmic ray modulation problem. It has been known for many years that the cosmic ray intensity in the inner solar system varies in antiphase with solar activity. It was understood that when the solar wind blows harder, carrying with it magnetic field structures, some of the arriving cosmic ray radiation was excluded, i.e. its intensity was modulated. It was generally accepted that the modulation was spherically symmetrical and centered on the Sun but a dramatic demonstration that this was wrong appeared in the last few years. Following the increase in solar activity in mid 1987 cosmic ray modulation was seen as expected near the Earth and even at the most distant spacecraft in the ecliptic plane. It was not, however, seen by the Voyager 1 spacecraft situated at 30° heliolatitude and 40 AU from Earth. The cosmic ray modulation seems closely related to the shape and tilt of the wavy current sheet which separates the northern and southern heliosphere. The current sheet remains close to the equatorial plane when the Sun is quiet but becomes severely warped at times of high solar activity. Ulysses' contribution to this field as it climbs out of the ecliptic plane is eagerly awaited.

The Galileo Jupiter orbiter and probe mission was successfully launched and dispatched on its complex interplanetary trajectory by the Space Shuttle in October, 1989. The mission has been substantially complicated by the decision not to use the Centaur booster. The spacecraft has already flown by Venus and is returning to Earth for a gravity assist manoeuvre in early December 1990 before setting off for the Jovian system by way of the asteroid belt. The orbiter is to perform the first detailed programme of studies of the Jovian magnetosphere including a pass deep into the magnetotail region and planned flights through potential or actual plasma wakes of various of the Jovian moons. The many entirely surprising features of the Jovian magnetosphere revealed by the two VOYAGER encounters leave much important science awaiting GALILEO's eventual arrival in orbit.

The GALILEO launch coincided with some very large solar particle events in the autumn of 1989. Energies emitted were high enough to penetrate to the surface of the Earth, one event being the largest since 1956.

It is interesting to note that whilst most of the events seen before 1980 originated in flares on the northern hemisphere of the Sun, most of those seen since then have come from southern hemisphere flares. Evidence is appearing that activity on the Sun, not only varies from one hemisphere to the other, but that conditions for propagating solar particles are also different in the two hemispheres. During the years since the Pioneer and Voyager spacecraft reached the distant heliosphere little evidence of significant solar events has been observed. Small low-energy events tend to be obliterated and become unrecognizable beyond 20 AU. It will be very interesting to study how these large events showed up at large distances and above 30° latitude.

New missions awaiting the final stages of approval this year include Cassini-Hugyens, a Saturn Orbiter/Titan Probe to be done jointly by NASA and ESA and CRAF (Cometary Rendezvous Asteroid Flyby).

It thus follows that this area of research is active with exciting programmes to come. Finally, it is important to note that, although the core research in space plasma science must be through *in situ* measurements from space platforms, there are worldwide ancillary programmes of ground-based observations of various kinds, with telescopes, radars, magnetometer chains, riometers, etc. Furthermore, unique measurements are made by means of balloon-borne instrumentation and instruments carried on sub-orbital rocket flights.

CHAPTER FIVE

RESEARCH IN ASTROPHYSICS FROM SPACE

1. Galactic and Extragalactic Astronomy 1989-90

Although a number of satellites have been launched in the last year, the field of Space Astronomy has, at first sight, been somewhat overshadowed by the difficulties experienced with the Hubble Space Telescope (HST) and by the delays to the NASA Astro mission. Nevertheless, very considerable successes are being achieved with the US COBE and German/US/UK ROSAT missions, which were being launched during 89-1990. In addition, much useful work will be carried out with the HST in the area of UV spectroscopy pending a revisit with replacement instruments that will include optical correcting elements.

The NASA astronomy programme includes the four Great Observatories; one (HST) has been launched, two (GRO and AXAF) are approved for launch in 1991 and 1997 respectively, and a fourth (SIRTF) is still being studied and has not yet obtained "new start" status from the US Congress. The continuing NASA Explorer programme includes a series of small to medium-sized astronomy missions which will be discussed below. In addition, the NASA "Scout-class" series of Explorer missions also offers possibilities for certain specialized astronomy studies. Priorities in Astronomy in general are at present being discussed by the Bahcall committee. The report of this group, which will be available in May 1991, should seek to establish priorities for the field of Space Astronomy in the early part of the next century.

The European Space Agency (ESA) continues with the Horizon 2000 programme, an activity which began in 1987. In the area of Astronomy the two major missions to be undertaken in the next 10-12 years are the comprehensive X-ray Spectroscopy mission (XMM) and the high-throughput Hetrodyne Spectroscopy mission (FIRST). Payload selection has been completed for XMM and instrument development has begun. Studies of the FIRST mission are continuing and developments in areas of related technology are being supported. In addition to these two major or cornerstone missions, the Horizon programme includes a number of medium-sized Astronomy missions. Two of these, HST participation and Hipparcos, date from the time before Horizon 2000 and have been incorporated into that programme. Both are already underway. The Infra-red Space observatory (ISO) mission is scheduled for launch in 1993. In addition a number of other proposed Astronomy missions are considered for selection as the next medium mission of the Horizon programme. This selection will take place early in 1992.

The USSR has maintained a substantial programme of scientific research using both free-flying satellites and payloads on the MIR Space Station. Several major Astronomy missions, namely Spectrum X-Γ Radioastron and a UV Observatory are planned for launch in the course of the decade.

The Japanese Institute of Space and Astronautical Science (ISAS) is undertaking a programme of scientific launches. The successful Ginga X-ray Astronomy mission is still operational and missions in Radioastronomy (VSOP) and a further X-ray mission (Astro-D) are planned for launch in the next five years.

The instrumentation involvements of other national programmes are included below under the appropriate photon energy range.

Infrared, Submillimeter and Radio Spectral Regions

COBE, the Cosmic Background Explorer, was launched on a NASA Delta rocket in November 1989. The scientific aims include the production of maps of the sky in 100 wavelength intervals over a spectral range extending from 1 micron to 1 cm. COBE is also searching for spatial anisotropies in the cosmic background radiation using instruments with a sensitivity of a few times

10^{-4} K. Interplanetary and interstellar dust, primeval and infrared galaxies and the stellar background can be discriminated by their spectra and mapped. Preliminary results include the measurement of the microwave background spectrum over its entire frequency range. An excellent fit has been obtained to a black body spectrum with a temperature of 2.735 ± 0.082 K. Apart from the already known dipole anisotopy, no other anisotopies have so far been detected in the preliminary data. Following the scheduled consumption of all liquid Helium coolant, analysis of the final sky survey data is in progress and results of improved statistical quality will shortly become available.

Work continues on the ESA Infrared Space Observatory ISO, which is a successor to IRAS. Its cryogenically cooled telescope will be equipped with four scientific instruments which will permit imaging, photometric, spectroscopic and polarimetric measurements at wavelengths from 2.3 to 200 microns. ISO, which is scheduled for launch in 1993, has a planned mission lifetime of at least 18 months. It will be operated as an observatory with two thirds of the observing time available to the general astronomical community. Instruments are being constructed by international teams led by principal investigators from France, Germany, the Netherlands and the UK.

NASA is proposing to replace the Kuiper Airborne Observatory, the KAO, with SOFIA; the Stratospheric Observatory for Infrared Astronomy. The KAO is a one-meter telescope carried to altitudes above 12 kilometers by a modified C-141 cargo jet. SOFIA is a proposed joint project of the U.S. and the FRG consisting of a 2.7 meter infrared telescope carried by a modified Boeing 747 SP aircraft. The Federal Republic of Germany will provide the telescope, bearings and pointing system while the U.S. will provide the modified aircraft. The involvement of an Italian group in the mission is also being discussed. SOFIA would have approximately 10 times the sensitivity of the KAO and would provide a flexible observing tool and test platform for decades to come.

The Space Infra-Red Telescope Facility (SIRTF) would, if approved, be the last in the series of NASA's Great Observatories Program. This cryogenically cooled telescope will exceed the sensitivity of IRAS by three orders of magnitude. There will be three instruments on board: a spectrometer, a direct imaging camera and a precision photometer capable of operation over a very broad range of wavelengths. SIRTF has a life of at least 5 years and will occupy a 100,000 km circular orbit. A new start in 1993 is anticipated with a launch towards the end of the decade.

A "Scout-class" Explorer program was started by NASA in an effort to provide a mechanism by which experiments could gain access to a fast-track (3 years) from laboratory to orbit. The program should enable launches of limited-scope missions about once a year. The first astronomy selection in this program is a submillimeter spectroscopic survey instrument.

Preparatory work is underway on ESA's Horizon 2000 cornerstone mission for submillimeter astronomy (FIRST). The science advisory groups have defined baseline concepts and an extensive industrial system definition study is underway. Several design concepts will be examined, for example a mission based on an 8m diameter antenna, a smaller mission with a 4m antenna and a number of options including the use of mechanical coolers, heterodyne receivers and incoherent detectors. The study will be completed in early 1991.

Very long baseline interferometry at radio frequencies is of interest to many nations because the achievable baselines and hence spatial resolution is increased dramatically when antennas in Earth orbit can be operated in conjunction with Earth-based arrays. The USSR is planning the Radiostron mission - an antenna in space - by the mid 1990's. NASA contributes to international participation by providing ground and tracking support. Another VLBI experiment, involving the space-based antenna VSOP, is being planned by Japan's ISAS. This project would also involve the United States and would be supported by the European ground-based VLBI network. NASA

would provide its Deep Space Network for tracking and would also arrange to receive transmitted data from the spacecraft.

Italian scientists will explore the infrared wavelength region with two balloon-borne telescopes: TIR, a 3-meter millimetric mirror and TRIP, a 25 cm near-infrared telescope. One of the main scientific goals is the study of the diffuse cosmic background, its anisotropies and its smoothness; all features of paramount cosmological relevance.

Optical and Ultraviolet Spectral Regions

IUE has begun its 12th year of continuous operation with no degradation in scientific performance. The project, a collaboration between ESA, NASA and the UK SERC, undertakes UV spectroscopy in the 1152 to 3200 Å wavelength region. The strength of IUE derives not only from its scientific contributions but also from its success as an international space observatory. IUE has demonstrated that facility- class missions which rely heavily on centralized data archiving and are operated in a Guest Investigator rather than a Principal Investigator mode of operation can be uniquely productive.

ESA's Hipparcos mission is dedicated to the precise positional measurement of some 100,000 selected stars brighter than B=13 magnitude. Target accuracies of 2 milliard seconds are achievable by the observational technique which employs a satellite in a geostationary orbit. The two fields of the telescope, which are offset 58 degrees from each other, slowly turn around the satellite's spin axis. The spin axis moves such that it precesses around the Sun 6.4 times per year. This scanning pattern ensures that the position of a particular star, relative to many other stars about 58 degrees away, is measured a large number of times. Hipparcos was launched on 8th August, 1989. It failed, however, to achieve its planned geostationary orbit and instead the spacecraft has remained in an elliptical transfer orbit. This failure had a number of serious consequences: use of the originally planned single ground station was no longer sufficient to recover the data. In addition it was feared that the unforeseen exposure to the trapped particle zones would significantly shorten the life time of the solar arrays and damage the optical elements. In the meantime it has become clear that the performance of all the key systems is nominal and is likely to remain so for a 2.5 - 3 year mission lifetime. The use of a number of additional ground stations has permitted an observing efficiency greater than 70% to be achieved. It has thus become apparent that essentially all of the original scientific objectives, namely 2m arc second positions, parallax and proper motions, can be achieved in the course of an extended duration-mission, although at a significantly greater operational cost.

NASA's Hubble Space Telescope (HST), the first of the Great Observatories program, was launched in May, 1990. HST is a 2.4 meter aperture diffraction-limited "optical" telescope having instruments permitting observations over a spectral range extending from 1150 Å to 1.1 micron with a subsequent upgrade extending IR performance to 2.5 microns. The six initial instruments are: FOC (Faint Object Camera) provided by ESA, WF/PC (Wide Field/ Planetary Camera), FOS (Faint Object Spectrograph), GHRS (Goddard High Resolution Spectrograph), HSP (High Speed Photometer) and FGS (Fine Guidance System, used in astronomy). ESA is contributing to the HST project the FOC mentioned above, the solar arrays, and scientific and technical support to the ST Science Institute at Baltimore, USA. European astronomers from ESA member states are guaranteed a minimum of 15% of the observing time on HST. Since the launch and early operation of the HST, it has been established that an error in the figuring of the telescope's primary mirror has lead to a significant degree of spherical aberration. Thus, while some 15% of the light from a point-source image is contained in a central core of about 0.15 arc sec in diameter, the remainder is distributed in a halo which is about 1 arc sec
in extent. The extended halos resulting from the aberration make it impossible for HST to register the faintest objects that it was originally designed to detect. Nevertheless, very valuable observations are being carried out with the help of image restoration techniques. In the distant star cluster 30 Doradus some 60 stars have now been resolved by the HST Wide Field Planetary Camera where only 27 could be discerned previously. The ESA Faint Object Camera has provided

high-quality images of Supernova 1987A in the Large Magellanic Cloud. These show for the first time the exploding outer envelope of the original star. It is fortunate that the HST programme has included from the start the possibility of revisiting the spacecraft after a three year interval to replace some of the instruments. It is believed that the spherical aberration can be corrected by the addition of appropriate optical elements to these replacement instruments so that the telescope would be restored to virtually its full performance.

The NASA ASTRO-1 payload will fly in the shuttle bay as part of the Spacelab programme. The mission includes three co-aligned far ultraviolet telescopes which employ spectroscopic imaging and polarimetric instruments operating down to a wavelength of 900 Å. Following several delays to the related shuttle launch during 1990, it is hoped that ASTRO-1 mission, which also includes a Broad Band X-ray Telescope will fly in early 1991.

The German/US/UK ROSAT mission was launched on NASA Delta rocket on 1st June 1990. The mission includes an Extreme UV (EUV) telescope provided by the UK which is surveying the whole sky in the wavelength range 60 to 200 Å. Prior to ROSAT, some 20 sources had been discovered in this wavelength range. In the course of a 5-day test survey, the UK instrument has discovered 44 sources. On the basis of our understanding of the EUV sky and in particular the transmission of the interstellar medium at these wavelengths, it seems likely that the all-sky survey of 7 months duration will yield a total of between 1000 and 2000 sources. The survey phase of the mission will last for seven months, after which both the X-ray and EUV telescopes will be used as as observatories in a broadly based guest investigator programme.

A further survey in the EUV wavelength range will be undertaken by the NASA Extreme Ultraviolet Explorer mission which is due to be launched in the latter part of 1991. Following a preliminary survey, a second deeper survey of 100 times greater sensitivity will be carried out within a 1 degree wide great circle on the sky. The mission also includes an EUV spectrometer which will undertake detailed studies of a number of the objects found in the survey.

ORFEUS is a joint experiment of the FRG Space Agency BMFT and NASA. ORFEUS will consist of a German one-meter-class telescope capable of operating in the ultraviolet between 500 and 1200 Å. The telescope will be deployed from NASA's shuttle cargo bay during the course of an 11-day mission aboard the German ASTROSPAS carrier and will carry three spectroscopic instrument packages. The spectrographs will be provided by the University of Tuebingen, the University of California/Berkeley and Princeton University. Launch is anticipated in 1992.

In 1989 NASA selected the Far Ultraviolet Spectroscopy Explorer (FUSE) mission for phase-B study in its Delta-class programme. This mission will undertake high resolution spectroscopic observations in the wavelength range 900 to 1200 Å. During 1990, the UK and Canada agreed to cooperate with NASA in the implementation and operation of FUSE, which is scheduled for launch in 1997.

X-Rays, Gamma-Rays and Cosmic Rays

Following the conclusion of operations with ESA's EXOSAT mission in April 1986, work has continued on the analysis of the large volume of data that was obtained during three-year operational life. Highlights include the discovery of Quasi-Periodic Oscillations in galactic X-ray sources, studies of accretion disc structure and a range of observations of stellar X-ray sources. The work is now greatly assisted by the availability of the EXOSAT data-base which is accessible to a large number of users both in Europe and the USA.

The hard X-ray and 2.5 to 25 keV coded mask telescope instruments on the USSR's KVANT module attached to the MIR Space Station continue to achieve interesting results. The latter instrument in particular, provided by a USSR (IKI)/Netherlands/UK consortium, has discovered more than 10 new sources in the Galactic Centre and Cygnus regions. In addition, several sources

of X-ray bursts in the neighbourhood of the Galactic Centre have been identified with specific X-ray emitting objects.

In Japan, ISAS continued to operate the highly successful Ginga mission whose main instrument is the large area proportional counter array, a joint ISAS/UK development. In addition to providing observations of the Supernova 1987A, work with data from Ginga has lead to a substantial advance in our understanding of the nature of Active Galactic Nuclei.

Although NASA does not, at present, have an X-ray or Gamma-ray mission in orbit, the Gamma-Ray Observatory (GRO), a part of the Great Observatory programme, will be launched during the first half of 1991. The GRO includes four instruments: EGRET, OSSE, COMPTEL and BATSE. EGRET, the Energetic Gamma-Ray Experiment Telescope, is a spark chamber instrument providing mapping, timing and spectral information in the 50 MeV to 10 GeV range. OSSE, the Oriented Scintillation Spectrometer Experiment, carries out broad-band spectroscopy in the 50 keV to 10 MeV region providing observations, for example, of the supernova tracer Aluminium 26. COMPTEL, the Compton Telescope, uses Compton scattering and two sets of scintillators to produce low-background maps at energies in the 1 to 30 MeV range. BATSE, the Burst and Transient Source Experiment, uses crystal detectors to search for gamma-ray burst and locates these to within approximately a degree. Hundreds of such detections are expected over the life of the experiment.

The German/US/UK ROSAT mission, launched in June, 1990 also includes an imaging X-ray telescope which is conducting an all-sky survey in the energy range 0.1 to 2.0 keV. The seven month long survey was started in July, 1990 and is proceeding successfully. The telescope, which employs a German-built imaging proportional counter and a US High Resolution (Microchannel plate) Imager, will be used in a three-nation guest investigator programme which will begin at the conclusion of the survey.

A Broad Band X-ray Telescope (BBXRT) will be flown on the ASTRO mission as a part of NASA's Space Shuttle-based scientific research program. In addition to the ultraviolet components described above, the BBXRT will be mounted adjacent to the ultraviolet instruments on a separate pointer. The BBXRT is designed for spectroscopy in the 0.3 to 10 keV range. The first ASTRO mission will be launched in early 1991.

XTE, the X-Ray Timing Explorer, is a part of NASA's Delta-class Explorer program. Three experiments comprise XTE: a large area proportional counter array operating in the 0.5 to 60 keV range, scintillation detectors for high energy X-ray timing in the 20 to 200 keV range, and an all-sky monitor which surveys approximately 80% of the sky every 30 minutes. The planned lifetime of the mission is 2 years. Launch is planned for the mid-1990s.

ASTROD-D is a joint mission of the Japanese space agency, ISAS and NASA. The experiment will use a US-built concentrator similar to that employed in BBXRT together with focal-plane instrumentation to perform high-efficiency imaging spectroscopy in the 1-10 keV range. The US will provide one of the focal plane instruments (an X-ray CCD) in addition to the concentrator. Launch is expected in 1993.

The Advanced X-Ray Astrophysics Facility (AXAF) is a part of NASA's Great Observatories program. The main optical system for AXAF consists of a set of 6 nested Wolter type I grazing incidence mirrors having an overall aperture of 1.2 meter. It is designed to work in the energy range 0.1 to 10 keV. The three focal-plane instruments are designed to include two imagers (one microchannel plate and one CCD based) and one spectrometer cryogenically-cooled calorimeter. High- resolution spectroscopy will be performed using transmission gratings in conjunction with the imaging detectors. AXAF will be launched in 1997.

IKI is planning an X-Ray satellite mission, Spectrum X-Gamma, to be built and launched into high elliptical orbit by the USSR. It will carry payload components provided by international

participants including X-Ray telescopes from Danish and UK-led consortia, an X-Ray polarimeter from a US-Italian-UK group and an X-Ray all-sky monitor from the United States. Current plans call for a launch in 1994.

The second ESA cornerstone Mission (after SOHO/Cluster) is XMM, the High-throughput X-Ray Astronomy Mission, for which the payload was selected in 1989. The telescope uses nested grazing-incidence X-Ray mirrors covering the energy range 0.1 keV to 20 keV. With a planned launch in 1998, the first and important step of technological demonstration of its mirror-fabricating techniques is well advanced, and the first replicated mirror shells have already been evaluated in the MPE "Panter" X-Ray calibration facility. The performance of these shells looks extremely promising. It is intended to operate XMM as an observatory having a satellite design lifetime of two years and a target lifetime of ten years.

There are two national projects being carried out by Italy: the X-Ray satellite SAX (jointly with the Netherlands), which should operate in the energy band 0.1 - 200 keV following a launch in 1993, and a balloon programme in X-and Gamma-ray astronomy. Characteristics of the instruments to be flown have been chosen and the specifications distributed to the institutions that proposed them. Some prototypes have been developed and flown on balloons. There are several balloon projects: PALLAS, LAPEX and POKER in the X-Ray domain; GAMTEL-ZEBRA, FIGARO and LIME in the Gamma-ray region.

2. Solar Physics

The understanding of the Sun, which had made many important advances in the first half of this century, reached a temporary pause during the 1940's, having to a large extent exhausted the analysis possible from the limited access to the visible spectrum as seen through the earth's atmosphere. With the arrival of spacerockets, the Sun provided the first object for space astronomy studied from the captured V2 vehicles in 1946. From that day on solar physics studies have been revitalized. Studies of the Sun has always remained in the forefront of innovative space research and today it is the most mature of all the space sciences.

Motivation for solar studies falls into three broad categories. As the nearest star and the only one for which we can exploit spatial resolution and have access to the entire electromagnetic spectrum, the Sun provides a unique point of interest for the physics of stellar evolution, structure and activity. The second area concerns the Sun as a plasma laboratory. The possibility of observing the behaviour of hot plasma, the fourth state of matter, in a near steady state, is not yet available on Earth. Solar studies bring enormous advantages to the exploration of the MHD phenomena and the collision physics and spectroscopy of of highly ionised atoms. The third area is that of solar-terrestrial relations. Emissions from the Sun dominate the earth's environment and provide the physical properties exploited by all aspects of life on the planet. This aspect, already crucial for understanding the balance of physical processes, becomes even more important with the increasing awareness of global change and the evolution of the environment produced by our industrial advance.

Solar Activity

In the past three decades the greatest advances in solar physics have come in the domain of high-energy emissions such as UV, EUV, X and gamma-ray photons, charged particles and neutrons. In particular, the Solar Maximum Mission, in orbit from 1980 to 1989, has made through its coordinated studies over a wide range of radiations, very significant advances to the understanding of flare phenomena. This emphasis on coordination will be a key element in many future projects. The space environment, (free of atmospheric effects harmful to observations) has also greatly advanced certain visible light studies by coronagraphs, which have contributed to our understanding of the role of solar magnetic fields and of transient phenomena in the interplanetary medium. The combined observation of high-energy emissions and magnetic field

dynamics represents a key strategy for understanding the mechanism of solar flares and other transients.

The Quiet Solar Atmosphere

Because the "quiescent" solar chromosphere and corona have such high temperatures, they must be observed at shorter wavelengths in the UV and EUV. The main problem here is to understand the mechanism whereby a small fraction of the mechanical energy present in the convective motion of the lower, cooler photosphere is transferred upwards to result in the heating of the corona and the acceleration of the solar wind. The Laws of Thermodynamics require that this transport be by non-thermal means since heat cannot be transported in the direction of a positive temperature gradient. Results from spaceborne instruments, such as those flown on Spacelab, rocket flights and other missions, with the invaluable cooperation from ground based observations, have clarified a number of issues. We now have a picture of the three-dimensional structure of temperature and density, as well as of the importance of continuous fine-scale dynamic effects in the solar plasma and in the related magnetic field structures. The scale of the participating structures ranges from the limit of present-day telescopes (a few hundred kilometers on the solar surface) to large-scale unipolar regions called coronal holes. The observations demonstrate clearly the critical role of small-scale magnetic field structures in the transport process. Some of the previously proposed transport mechanisms can now be excluded and there are some very positive pointers to the correct interpretation. Theoretical models based on wave transport or stochastic processes may, in the end, be equivalent, since any wave interpretation must involve extreme nonlinear amplitudes.

The Solar Interior

The techniques of space research are now being brought to bear on the understanding of the structure and dynamics of the solar interior and convection zone, in exploiting the new field of helioseismology. This field, developed over the past 20 years using observations from the ground, studies the modes of vibration of the global Sun and interprets them in terms of the internal physical properties. Making observations in space removes the two obvious limitations of the day/night eclipsing and the atmospheric degradation. In particular, vehicles which orbit far from the Earth offer the possibility of long periods of uninterrupted solar viewing. The first space observations in a near-earth orbit were obtained from the SMM satellite. More recently, many months continuous data have been obtained from the Soviet Phobos spacecraft while on route to the planet Mars. Three ambitious experiments are planned for the SOHO mission. These observations will help resolve the questions posed by the enigmatic low solar neutrino flux, as well as by the internal differential rotation, convection and the generation of the solar magnetic fields.

The Solar Interplanetary Connection

Studies of the corona from space have shown the importance of the so-called "coronal holes", large areas of the solar surface with well defined boundaries, in which the corona has a much lower density. It is now accepted that these areas are those with an open field structure connected directly to interplanetary space. They are the major source of the steady solar wind and their understanding is thus crucial to the problem of solar (and stellar) mass loss and ultimately for stellar evolution. Their relation to the solar wind has so far been studied only in the ecliptic plane. With Ulysses it will be possible to examine the role of the polar coronal holes, which it is thought could show a significantly larger wind flux.

Future Missions and Programmes

There are now two major thrusts in the new missions currently planned. The first covers the study of activity during the next solar maximum in cycle 22 with missions such as Solar A, balloon projects and the Flares 22. The second relates to the quiet solar corona and its interaction with the interplanetary mission, with the missions Ulysses, Wind, Coronas and SOHO. In addition,

opportunities will be exploited to pursue the techniques of helioseismology (SOHO), as well as to capitalise on the solar observing capabilities of certain astronomical missions (Sigma and GRO).

-Solar A

The Solar A mission, to be launched by Japan in 1991, will carry a complement of instruments to monitor energetic flare phenomena and the evolution of coronal magnetic structures. This will be the only satellite totally devoted to solar observations during the next maximum. Its payload includes a high resolution soft X-ray telescope provided by the USA and a Bragg crystal spectrometer developed jointly by experimenters in the UK and USA. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope, which will have considerably improved sensitivity, energy range, and spectral resolution over imaging detectors previously flown aboard the SMM and Hinotori missions. Higher energy X-rays, gamma rays and neutrons will also be monitored by Solar A instruments. Significant improvements in temporal resolution, eg. 2 seconds in gamma ray spectra as compared to the 16 seconds of the SMM spectrometer, should provide new insights into the understanding of the particle acceleration and interaction processes in flares.

-Ulysses

Ulysses, formally known as the International Solar Polar Mission, was launched in October 1990 on its long journey to study the solar poles from outside the ecliptic plane. It will use the gravitational field of Jupiter to deflect its trajectory to pass over both solar poles at a distance of around 1 AU.
Ulysses carries a variety of particle detectors for studying the solar wind *in situ* as well as two small scintillation detectors for observing X-rays from 15 to 150 keV. It is thought that much of the solar wind seen in the ecliptic plane at 1 AU arises from the solar polar regions. It is therefore highly probable that the wind that we know at present is not typical of the general solar wind, which might be quite different perpendicular to the ecliptic plane. Ulysses thus offers the possibility of very important advances in understanding solar evolution and mass loss.

-Sigma

Sigma is a French experiment aboard the Soviet Granat satellite. Although its main objective is to map the gamma-ray sky and to locate non-solar sources, its cosmic gamma-ray burst detectors can also obtain flare spectra up to energies of 100 MeV. Sigma can also make high sensitivity and temporal resolution observations of flare emission in the 50 keV to 7.5 MeV range.

-Wind

The Wind spacecraft, a component of the Global Geospace System (GGS), which is part of the International Solar-Terrestrial Program (ITSP), will carry a high-purity germanium detector of solar flares and cosmic gamma-ray bursts in the 25 keV to 8MeV energy range. In addition to gathering information on gamma-ray lines due to accelerated particles in large events, the spectrometer will provide nearly continuous monitoring of hard X-ray emission from flares with spectral resolution superior to that of the SMM spacecraft.

-Gamma-Ray Observatory

The Gamma-Ray Observatory (GRO) is NASA's next major mission in high-energy astrophysics. GRO, which is scheduled for launch early in 1991, will carry four large instruments with the objective of obtaining comprehensive observations of cosmic sources in the 20keV to 30GeV energy range. GRO is also well suited for observing of solar radiation - gamma-ray and accelerated neutrons - which are evidence of the most energetic processes occurring in flares. Of

the four instruments the Burst and Transient Source Experiment (BATSE) will have the greatest capability for flare observations due to its large sensitive area. It should provide extensive high temporal resolution observations of flare emission in the 50 to 1000 keV energy range. Observations of the nuclear line region of the spectrum will be provided by two other instruments, the Oriented Scintillation Spectrometer and the Imaging Compton Camera (COMPTEL), while the Energetic Gamma-Ray Experiment and the Telescope (EGRET), which covers the 20 keV to 30 GeV portion of the spectrum, will probe the most energetic phenomena on the Sun.

-Coronas

Coronas is a series of Soviet satellites planned for launch starting in 1992 and aimed at observing from near-earth orbit the solar atmosphere, solar activity, and magnetospheric solar effects. They will carry a number of instruments developed by Soviet groups in collaboration with many other countries. Current plans include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as studies in helioseismology.

-Balloon Programs

Several countries, including China and the USA, have plans to carry out balloon observations with dedicated flare physics oriented instruments. Many of these will be carried out in the long-duration balloon flights. In the case of the USA, the Max 91 program includes the flight of the High Resolution Gamma-Ray and Hard X-Ray Spectrometer (HIREGS), which will be able to investigate the region 15 keV to 20 MeV with high spectral resolution.

-The International Flares 22 Project

In an international effort modelled after the successful Solar Maximum Year (SMY) program of the early 80's, the world-wide solar community will join forces once again on a program of flare research at the maximum of cycle 22. Flares 22 will be an integral part of the Solar Terrestrial Energy Program (STEP); sponsored by the Scientific Committee on Solar Terrestrial Physics (SCOSTEP). Research on active phenomena will require the analysis of data from many individual spacecraft and balloon experiments as well as highly improved ground-based observatories. Flares 22 will focus international attention and collaboration on the analyses of these data and on the theoretical work they inspire.

-SOHO

ESA, in collaboration with NASA, is developing the Solar and Heliospheric Observatory (SOHO) due to be launched in 1995. It will orbit the L1 Lagrangian point at 1.5 million kilometers from the Earth, a location that offers continuous viewing of the Sun and an ideal site for *in situ* wind measurements and helioseismology. Soho is the most ambitious solar project developed so far. Its instruments will probe the entire Sun, its centre by means of helioseismology, its outer atmosphere by remote sensing visible and UV observations and the wind at 1 AU by *in situ* studies. Instruments are being provided by European and US consortia. The helioseismology instruments include GOLF (Global Oscillations at Low Frequencies), VIRGO (Variability of Solar Irradiance) and MDI/SOI (Michelson Doppler Imager). These will measure global oscillations, the solar radiative output and surface magnetic fields. A detailed study of the solar atmosphere from the chromosphere to the corona is the subject of CDS (Coronal Diagnostic Spectrometer), SUMER (Solar Ultraviolet Emitted Radiation) and EIT (EUV Imaging Telescope). The higher corona will be observed by UVCS (Ultraviolet Coronograph Spectrometer) and LASCO (white light and spectrometric coronograph). Combined, these instruments can measure the temperature, density, composition and velocity of solar plasma at various heights with the aim of deriving the balance of energy and mass up to a height of 30 solar radii. SWAN (Solar Wind Anisotropies), CELIAS (Charge Element and Isotope Analysis), COSTEP (Comprehensive Suprathermal and Energy Particle Analyser) and ERNE (Energetic and Relativistic Nuclei and Electron Experiment will

probe many aspects of the solar wind. These instruments will study the wind structures and relate them to coronal structures and dynamics.

-Projects for Future Missions

Studies are underway for a number of projects based upon the obvious need to continue the advance of solar physics in the next century. OSL, with a minimum lifetime of three years, is an observatory-type mission in a polar orbit, which would provide continuous data in white light, UV, EUV images and spectra, with 0.1 arcsecond resolution. It includes a 1-meter telescope feeding a number of focal plane instruments. The ASO would be a quasi permanent space observatory; of which the OSL concept would eventually form a part. Other instruments under study for these facilities include the Pinhole Occulter Facility for imaging high-energy X- and Gamma-radiation at 0.2 arcsecond resolution, and instruments for high resolution interferometry and Fourier transform UV spectroscopy.

These ideas could serve to ensure a bright future for solar physics at the start of the next millenium.

CHAPTER SIX

LIFE SCIENCES AND SPACE RESEARCH

1. Gravitational Biology

Space Medicine

During the reporting period human expeditions of 167 and 179 days duration were carried out in space on board the orbital complex MIR; another long term mission with two cosmonauts on MIR started in August, 1990. Besides a complex scientific flight program (such as fundamental and applied research in the field of gravitational biology, physiology and medicine) the main goal was to maintain good health conditions and high work capacity of the crew. This endeavour included the optimization of crew habitats, the improvement of the life support systems and measures to counteract the impact of a multi-month spaceflight on the human body as well as improvements in the reliability of radiation safety systems during space missions. The ultimate goal is to preserve the functional capacity of the crew throughout long term missions, which include periods of extravehicular re-adaptional activity. The efficiency of the medical support system has also been increased to reduce re-adaptional disorders in the human body when returning to Earth conditions.

Since the U.S. Space Shuttle resumed its flight in October, 1988, the emphasis on manned missions and its associated research in human physiology has gained momentum in the western world. In particular, in preparing the Space Station scenario, the U.S. are putting emphasis on the studies of the human body's reaction to 16-20 day missions in weightlessness.

The biomedical research program on board MIR yielded new data on the dynamics of venous pressure during long-term flight. A series of neurophysiological and psychophysiological investigations were carried out to characterize health conditions and the responses of the sensory system.

Space Biology

The instalment of new biological research modules on MIR, such as Kvant-2 and Cristall, allowed unique biological studies on higher plants, e.g. Greenhouse-Svet-Experiment, and on small animals, e.g. development and life span of the Japanese quail. These experiments, carried out with international participation, helped answer vital issues of gravitational biology. They also provided important basic information for the creation of ecological life support systems for future generations of autonomous space complexes and of interplanetary manned vehicles.

The resumption of the U.S. Shuttle flights has given the Spacelab missions significant momentum: SLS-1 and SLS-2, and IML-1 and 2, D-2, and future M-missions (Multinational) will soon start and work on the backlog of some hundreds of biological experiments already selected in the life sciences. The studies, which will be performed in international cooperation, include experiments at the molecular and cellular levels, as well as studies on tissues, plants and animals (including mammals).

The Soviet Biocosmos (Cosmos 2044, launched in September 1989) which contained primates, rodents, plants, tissues, bacteria etc, yielded a wealth of information on living systems' reaction to both weightlessness and to cosmic radiation. The experimental data will be presented in Moscow at an international symposium in May 1991. This mission, probably larger than any previous, involved widespread international cooperation including Western European countries and the United States: some 200 scientists participated, of whom many actively supported the research on this mission. The results of some of the studies, which were carried out on board the previous Biosatellite mission (Cosmos 1887) are published in a special report.

Further Activities

Operation of the MIR complex (under conditions of manned mission) will continue (providing that the complex be expanded by the introduction of additional specialized modules and the interaction with the Shuttle space system BURAN). Space expeditions on the MIR complex up to the year 1992 involve extensive international cooperation with the participation of astronauts from Japan, Great Britain, Austria, France and Germany. Further extension of cooperation among the USSR, European States and the USA in the field of manned spaceflight is under way.

The planning of "free flyer" unmanned satellites, retrievable from low Earth orbits, has also attracted the interest of the life sciences community. These research platforms, e.g. "Lifesat" in the U.S. and "Raumkurier" in Germany, have the advantage of being comparatively cheap and more easily accessible with a higher launch rate compared to manned systems. The Soviet Biocosmos missions are typical in this context. The experiment preparation for the next Biosatellite, which is to be launched in 1992, is in progress; the experiments will include physiological research on the effects of weightlessness on two rhesus monkeys, amphibians, insects, seeds and cellular and tissue crops to be carried out in cooperation with NASA and ESA.

For the planned space station Columbus, studies are in progress for large scale biological research facilities such as Biolab, Physiolab and Anthrolab. In addition, scientific studies related to biomedical problems in future manned missions to Moon and Mars have also been started.

2. Radiation Biology

Proton radiation predominates on missions in low-Earth orbit. In deep space not only protons, but also heavy charged particles contribute to the radiation environment. It is the radiobiology of the heavy charged particles that is of particular concern. There is dense ionization along the particle track, and in the case of the higher Z particles the track may traverse a considerable number of cells. The high density of the ionization along the track results in a high radiobiological phenomena for certain effects. It is therefore essential to understand both the early and late effects of heavy charged particles in order to estimate the risks of prolonged sojourns in space.

It is not only the effects of radiation in space that must be understood but also the effects of microgravity. The question of whether or not radiation and microgravity interact is an important one which can only be answered by studies in space.

Ground Research

The number of particle accelerators which are suitable for studying the effect of heavy energy ions and high Z in the worker is limited and research is concentrated at the GSI accelerator at Darmstadt, Germany, at the Joint Institute of Nuclear Research at Dubna, USSR, and the Bevalac at Berkeley, USA. Studies have been carried out on high energy heavy ion propagation in order to determine the radiation environment in space vehicles and for the design of shielding. An important characteristic of heavy charged particles is fragmentation caused, for example, by the vehicle shielding. The effect of fragmentation, the interactions of particles and matter and the production of secondary particles are all under study. The progress made so far in the definition of the possible radiation environments within space vehicles will help in the design of the shielding required.

The effects of exposure to HZE particles, which are currently being studied, include damage to DNA, mutation, malignant transformation, cataract induction, changes in behaviour and biochemical activities in the brain and life shortening. It has been shown that HZE particles are more effective than other radiations in the production of many biological effects.

Research in Space

A considerable amount of dosimetry and testing of methods and equipment has been carried out in the last year during USSR and US missions. A portable tissue equivalent proportional counter spectrometer has been introduced and tested. The report of the collaborative study of radiation experiments on the 12.6 day COSMOS 1887 Biosatellite system involving scientists from Czechoslovakia, France, Germany, Netherlands, United States and USSR was published in 1990. More precise measurements of the dose and energy and LET spectra than previously available have been obtained for low Earth orbit missions from work in a number of countries.

On board the "Long Duration Exposure Facility" of NASA, different biological samples such as spores, seeds and shrimp cysts were exposed to a high influx of cosmic radiation for nearly 6 years. A series of experiments of the Biostack type allowing localization of the trajectory of single particles in biological layers will provide basic information on the impact of radiation in space on biological integrity during long term missions.

The possibility of an interaction between radiation and microgravity has long been recognized but as yet not determined quantitatively in an adequate manner for the understanding of potential risks. Recent work indicated that the combined exposure to HZE particles and microgravity act synergestically on eggs of a simple organism and can result in developmental anomalies. More research is required to establish the combined effects of radiation and microgravity on various cell systems and cellular functions.

3. Planetary Biology and Origins of Life

Space Dust Particles, Comets and Chemical Evolution on Terrestrial Planets

The encounter missions GIOTTO and VEGA 1 and 2, for the first time allowed the direct study of the chemical, isotopic and molecular composition of cometary grains. The evaluation of the data leads to the following conclusions: (1) The dust particles contain variable proportions of silicates and organic components containing the elements H, C, N, and O. (2) The organic components are rich in unsaturated and N-containing carbon compounds. The abundances of the bioelements C, H, O, and N are higher than in carbonaceous chondrites and approach the solar values.

Estimates suggest that comets and other primitive solar system bodies, captured by the primitive Earth during the Archean, must have been the major source of terrestrial volatiles. It is, however, likely that a substantial fraction of the organic compounds present in the cometary nuclei were destroyed due to the high temperatures and shock wave energy generated during the collision with the Earth. Simple compounds or molecular fragments could have survived the collision and given rise to a huge variety of organic compounds in post-collisional reactions. It is likely that similar processes have occurred on early Mars. An accumulation of convincing evidence demonstrates that liquid water may have existed on early Mars for about 700 million years.

Biochemical Evolution on Early Earth

Research has continued to focus on the following issues:

-Were the first enzymes nucleic acids?
-Can nucleic acids replicate themselves and synthesise peptide bonds without the help of proteins?
-How and when did the chiralic systems (optical activity) originate?
-How did the early bioenergic pathway evolve?
-How did genetic information originate?

There is widespread agreement that the co-evolution of peptide and ribozyme synthesis was a plausible development and that the RNA preceded double-stranded DNA.

Life in Extreme Environments

Research has focussed on the question: By what strategies could terrestrial organisms survive under the extreme conditions of Mars? It has been demonstrated that the DNA, even of the most dry-resistant organisms, suffers an increasing number of double-strand breaks during long (i.e. month long) exposure to environments with very low partial pressure of water vapor. These data allow the prediction that the survival of the most dry-resistant terrestrial life forms (dormant life) is possible for many decades, even centuries, but not for geological periods of time. Therefore, if there is extant life on Mars today, it can only be found in ecological niches (hydrothermal veins, deep in the ground or under thick ice layers) where liquid water is available. It is not plausible that dormant life could be found in areas that have been dry for geological periods of time. Strategies for seeking evidence of life on Mars (whether extant, fossils or precursors) are being considered by NASA and ESA (MEST-Study).

Experiments in Space

The use of free-flying satellites for exobiological research in space has been studied by ESA. The following questions have been identified for consideration:

- -Relevance of extraterrestrial molecules to the emergence of life on Earth or on any other planet;
- -Role of solar UV radiation in evolutionary processes related to life;
- -Chances and limits of life being transported from one body of our solar system to another or beyond;
- -Exobiological phenomena in aerosols and clouds.

The preparation of the experiments of the Exobiology Radiation Assembly (ERA) of the European Retrievable Carrier (EURECA), which is to be launched in 1991, is being completed. They include investigations on the formation, stability and destruction of organic molecules and polymers as well as on the biological responses to solar UV in space such as genetic changes of viruses, bacterial and fungal spores or nematodes.

4. Natural and Artificial Ecosystems

Biospherics

To elucidate the interaction of the biosphere with its environment on Earth (atmosphere, hydrosphere, lithosphere), theoretical models as well as remote sensing techniques are used. Remote sensing technology has been applied to a variety of studies on wild fires, malaria and other vector borne diseases, biomass estimation, pollution control and the ozone problem. Experiments carried out in temperature and tropical rain forests have examined nutrient cycling, particularly nitrogen. Forest-level estimations of photosynthesis based on airborne measurements of CO_2 have been undertaken and appear promising. Carbon dioxide cycling models have been expanded to include effects of continental margins, seasonality effects based on temperature, and exchange across the air-sea interface.

Controlled Ecological Life-Support Systems

During the reporting period, advances have been made in the development of bioregenerative life support systems that make use of growing plants, supported directly or indirectly by sunlight and capable of using a space crew's carbon dioxide to produce food, oxygen and potable water. Various aspects of this approach to life support are currently under investigation by scientists in the USA, Japan, the USSR, France, Germany and Canada. Pilot experiments are being planned for the forthcoming space missions by the USA and USSR.

Recent work has begun to address issues of the total spacecraft ecological system, which includes humans, plants, animals and microbial organisms. The need for artificial ecosystems on extra terrestrial bases, such as the Moon or Mars, is another topic of intense investigation.

CHAPTER SEVEN

FLUID AND MATERIALS SCIENCES, MICROGRAVITY SCIENCE AND SPACE APPLICATIONS

Microgravity Science and Applications include: basic and applied research in fundamental science (relativity, condensed matter physics, fluid dynamics and transport phenomena, combustion science); materials science (electronic and photonic materials, metals and alloys, glasses and ceramics) and biotechnology (protein crystal growth, separation science, cell science) studied in the absence of gravity. Experiments conducted under these conditions can clarify the roles of factors normally masked by, or competing with gravity induced phenomena (i.e. sedimentation, convection and buoyancy) in complex physical processes. The elimination of hydrostatic pressure in the absence of gravity may also be used to make critical fluid measurements which are not possible on Earth. The resulting contributions to science may be applied to advance the state of both Earth and space-based technology. The quiescent space environment may also be exploited to process selected materials in unique ways. For example, both organic and protein crystals of a composition, size, quality and uniformity unattainable on Earth may be obtainable in space. These and other space processed materials may have important applications, e.g. in the development of new pharmaceutical products and advanced engineering materials.

1. Fundamental Sciences Research

Fundamental sciences research includes studies of gravitational theory, the behaviour of fluid transport phenomena and combustion science in microgravity. A fundamental assumption in Einstein's Theory of Relativity is the equivalence of gravitational and inertial mass. NASA is sponsoring research that may lead to an equivalent principal experiment to extend the precision of these experiments to one part in 10^{17}. A critical piece of test hardware was developed to measure the test mass position and to evaluate the dynamic behaviour of the test mass in the apparatus' magnetic bearing. A major study detailing the science requirements and including a comprehensive error analysis was completed. Ground based research aims at understanding critical point behaviour in general and in microgravity helium physics in particular. In one study, investigators are pursuing the measurement of fluid viscosity near the critical point. This research directly supports the Lambda Point flight experiment. A complete set of all useful critical point viscosity data for single component fluids have been collected under 1g conditions. The analysis of these data will enable refinements of the requirements for a space-based experiment to complement the Critical Fluid Light Scattering Experiment already under development. Another activity involves the investigation of critical transport properties and fluid and interfacial transport properties of liquid helium under low gravity. Fluid and interfacial transport phenomena are central to a large number of physical, chemical and biological processes. Microgravity researchers in the U.S. and Europe are conducting several ground- based investigations of phenomena critically affecting the growth of inorganic and organic crystals in the microgravity environment. One study investigated the effects of small, non-zero accelerations on crystal growth. These results will be used to help define vibration isolation requirements aboard manned space-based research platforms. In another study, a Monte-Carlo type of analysis was applied to predict the size and shape of crystals grown from the vapor phase in the presence or absence of buoyancy-induced flows. Computer-generated predictions of growth patterns of typical crystals indicate that fractal geometries, in which the shape and "fill factor" of the entire crystal is related to any small element of it, will result under certain well defined conditions. The study of combustible particle clouds is of fundamental scientific interest as well as of practical concern. An experimental study of quiescent, uniform particle clouds has not been accomplished in normal gravity due to particle settling; however, low gravity conditions obtained using Learjet aircraft have already produced anticipated flame front and wake structures in suspended particle clouds. Experimental and theoretical progress in premixed gas combustion has been made through the study of stationary "flame bubbles" stabilized by radiative and diffusive transport. These flame bubbles are of great interest since they are probably the only fundamental flame structure in which convective transport plays no role.

2. Research in Materials Science

Research in materials science includes the processing of electronic and photonic materials; metals and alloys and composites; glasses, ceramics and polymers. A technique for growing L-arginine phosphate crystals has been developed. This material has interesting non-linear optical properties and could have applications in opto-electronics, laser conversion and nuclear fusion technologies. Large optically clear crystals up to 20 mm by 10 mm by 5 mm have been grown. The characterization of the physical and optical properties of these crystals as well as further tests to determine the reproducability of these properties is currently underway. Numerical modelling was used to study fluid flow during solidification of gallium arsenide (GaAs)in a planned crystal growth flight experiment. The results indicate the importance of the acceleration vector relative to the crystal axis in establishment of complex three-dimensional flow fields. Containerless processing of pure refractory metals and niobium-based binary alloys have been studied. Solidification velocities of undercooled pure niobium were studied under microgravity conditions. Because experimental results did not correlate well with predictions from established theory, additional tests are underway. Since the historical discovery of high critical temperature (T_c) oxide superconductors, some compositions have been shown to form glasses. In preliminary nucleation experiments with reluctant glass-forming bismuth-oxide glass semiconductors researchers have shown that the nucleation temperature is a function of cooling rate.

3. Research in Biotechnology

The benefits of the microgravity environment to biotechnology research are currently being investigated. Ground based research on growing various protein crystals in preparation for a flight experiment has resulted in the growth of crystals of human serum albumin (HSA). As a result researchers were able to determine the three dimensional molecular structure of this protein to a resolution of 6 Å. This finding was a breakthrough in the area of rational drug design because the HSA molecule is important to the transport of many biological and pharmaceutical molecules in the bloodstream. Researchers have continued to refine the analysis and testing of electrohydrodynamic effects of soluble molecules at varying concentrations with fixed conductivity and at various pH, ionic strengths, and sample-to buffer conductivity ratios. State of the art bioreactors are being used to simulate some aspects of microgravity in order to obtain three-dimensional tissues rather than a flat sheet of cells that is typically obtained using traditional culture techniques. Results to date indicate that some human primary cell cultures (e.g. colon epithelial cells and lymphocytes) can be grown in greater quantities in bioreactors than in traditional cell culturing equipment. Tissues formed during the culturing of human tumor cells have produced detectable factors not previously identified.

Several important experiments are currently being prepared for Shuttle flights. These include payloads of varying complexities, ranging from relatively simple, highly automated experiments in "Get Away Special" cannisters carried in the cargo bay, to complex multi-rack experiments requiring substantial crew interaction. At present, the first flight of the U.S. Microgravity Laboratory, to be carried aboard the Spacelab in 1992, represents the highest priority near-term flight opportunity for U.S. microgravity experiments. Four major experiments, including the Drop Physics Module, the Crystal Growth Furnace and Surface Tension Driven Convection Experiment, and the Solid Surface Combustion Experiment, are scheduled for that mission.

Opportunities for space-based research into the fundamental sciences, materials sciences and biotechnology has prompted innovative and important experiment proposals from the U.S. and international scientific communities. The potential rewards of the microgravity program include a deepening of our understanding of physical processes in our environment, advancements in technology in numerous engineering disciplines, and improvements in the quality of life on Earth. In addition, the knowledge gained from space-based microgravity research may lead to important commercial applications.

CHAPTER EIGHT

SATELLITE DYNAMICS

The most interesting results in the field of the orbital determination and analysis are summarized below:

1. Interplanetary Missions

After the spectacular Voyager 2 flyby of the planet Neptune on August 24 1989, we have another example of the skillful use of the laws of celestial mechanics in the Galileo mission to Jupiter. High accuracy trajectory determination is essential to the success of most interplanetary missions.

2. Practical applications of the Earth-orbiting satellites

The satellite Lageos is continuously tracked by a worldwide network of laser ranging stations. The orbit of Lageos is a reference for monitoring the variation of the Earth's rotation and for determination of global dynamics.

The Global Positioning System (GPS) is used more and more for both very precise positioning on the Earth and for satellite navigation in space. In order to fulfill the requirements of high-precision GPS orbits, independent services have been organized in the USA, Canada, Australia and Europe. Precise GPS methods can give positions on the ground with centimeter accuracy, if the satellite's position in space is determined with an error ± 1-2 m.

CHAPTER NINE

SCIENTIFIC BALLOONING

The subjects of the papers presented at the COSPAR Symposium on Scientific Ballooning (The Hague, July 1990) provide a representative sample of current activities in this field.

There is intense activity in the development of new balloon films due to the failures reported some years ago. The problems have been analyzed and solutions were found. Not only have new products appeared on the market, but theoretical analyses and design studies have also been performed.

The continuous growth and complexity of balloon payloads makes long duration flights necessary to compensate for the high costs. Groups within NASA, as well as Japan and France, are very active in this field.

Efforts in instrumentation are dominated by the astrophysical sciences. Their payloads are most involved and require thorough planning. X-ray, gamma-ray, infrared and UV radiation detectors are the standard equipment for many campaigns. In addition, in the field of atmospheric chemistry, some research is being done but there are also activities in atmospheric chemistry (measuring aerosols, nitric acid etc) which use mass spectrometers.

A new application for balloons is arising in the field of planetary research. The planet Venus was the target of a Soviet space mission which used balloons for the exploration of its planetary atmosphere (co-operative effort with France). Future interplanetary space activities will focus on the planet Mars and some interesting balloon experiments are planned in this context.

In conclusion, balloon experiments in the stratosphere and planetary atmosphere are a well-established means for carrying out scientific research. The development of new balloon systems and materials goes hand in hand with scientific efforts. Activities could be noted in all traditional fields, but also new ideas such as planetary balloons enter the scene. Most of the efforts in developing balloon research is taking place in Japan, India, France, the USA and the Soviet Union, but there is continued interest in other countries as well.

CHAPTER TEN

SPACE RESEARCH IN DEVELOPING COUNTRIES

The COSPAR Panel on Space Research in Developing Countries, created in 1983, is devoted to the promotion of space research in Third World Countries. Since 1986 the Panel has been receiving modest annual grants from ICSU-UNESCO. Following earlier tradition, the Panel has been making grants from this subvention to scientists from developing countries to attend scientific sessions; about ten grants were made during this year. This money is judiciously used for purposes such as travel fellowships for attending scientific meetings and training courses, spare parts for scientific instruments, satellite data tapes and similar needs.

During the biannual COSPAR Plenary Meetings an important activity of the Panel is to organise a workshop on topics of importance to the Third World. At the 1990 Meeting, a workshop on the Equatorial Electrojet was organised and since a large number of Third World Countries are located in tropical regions, this topic was found to be most appropriate. As in previous years, this workshop was also co-sponsored by the UN and COSTED.

From next year onwards the Panel (jointly with the ICSU Scientific Committee on the International Geosphere Biosphere Program and the Committee on Science and Technology in Developing Countries) is planning to organise promotional workshops and training programs. Such programs are seen to be in recognition of the imperative need for developing countries to participate in international programs on topics relating to environment and global change, and taking due note of the role of space observations in such studies.

On the basis of experience gained by the Panel during recent years, it has become evident that, if larger funds were available, many more relevant and needed activities could be implemented.

LIST OF ACRONYMS AND ABBREVIATIONS

AIRS	=	Atmospheric Infrared Sounder
AIRSAR	=	Airborne Multifrequency Polarimetric SAR
AMSU	=	Advance Microwave Sounding Unit
AVHRR	=	Advanced Very High Resolution Radiometer
AVIRIS	=	Airborne Visible Infrared Imaging Spectrometer
AXAF	=	Advanced X-Ray Astrophysical Facility
BATSE	=	Burst and Transient Source Experiment
BBXRT	=	Broad Band X-Ray Telescope
BEST	=	Tropical Energy System Budget
BOREAS	=	Boreal Ecosystem Atmosphere Study
CCIR	=	Consultative Committee International Radio
CELIAS	=	Charge Element and Isotope Analysis
CEOS	=	Committee on Earth Observation Satellites
CGMS	=	Coordination of Geostationary Meteorological Satellites
CMM	=	Commission for Marine Meteorology
COAP	=	Centre for Ocean Analysis and Prediction
COMPTEL	=	Compton Telescope
CRAF	=	Cometary Rendez-vous Asteroid Flyby
CZCS	=	Coastal Zone Colour Scanner
DMSP	=	Air Force Defense Meteorological Satellite Program
ECSAT	=	Experts on Satellites
EOSAT	=	Earth Observation Satellite Company
ERBE	=	Earth Radiation Budget Experiment
ESA	=	European Space Agency
EUMETSAT	=	European Meteorological Satellite Program
EUV	=	Extreme Ultraviolet
F0S	=	Faint Object Spectograph
FAA	=	Federal Aviation Administration
FGS	=	Fine guidance system
FIFE	=	First ISLSCP Field Experiment
FIRST	=	High Throughput Heterodyne Spectroscopy Mission (ESA)
FY-1B	=	Fen Yung-1B
GCM's	=	General Circulation Models
GEWEX	=	Global Energy and Water Cycle Experiment
GGS	=	Global Geospace System
GMS	=	Geostationary Meteorology Satellite
GMS-4	=	Geostationary Meteorological Satellite Number 4
GOES	=	Geostationary Operational Environmental Satellites
GOLF	=	Global Oscillations at Low Frequencies
GOMOS	=	Occultation Spectrometeory
GRO	=	Gamma-Ray Observatory
GRSFE	=	Geological Remote Sensing Field Experiment
GVI	=	Global Vegetation Index
HIREGS	=	High Resolution Gamma-Ray and Hard X-Ray Spectrometer
HSP	=	High Speed Photometer
HST	=	Hubble Space Telescope
ICE	=	International Cirrus Experiment
IFEOS	=	International Forum on Earth Observations Using Space Station Elements
ICSU	=	International Council of Scientific Unions
IKI	=	Institute for Space Research (USSR)
IOC	=	Intergovernmental Oceanographic Commission

IPOMS	= International Polar Orbiting Meteorological Satellite Group
ISAS	= Institute of Space and Astronautical Science
ISCCP	= International Satellite Cloud Climatology Project
ISLSCP	= International Satellite Land Surface Climate Project
ISO	= Infrared Space Observatory
ISTP	= International Solar Terrestrial Physics Program
ITU	= International Telecommunication Union
JIC	= Joint Ice Center
JPOP	= Japanese Polar Orbiting Platform
LASCO	= White Light and Spectrometetric Coronagraph
LFC	= Large Format Camera
MIMR	= Multichannel Imaging Microwave Radiometer
MODIS	= Moderate Resolution Imaging Spectrometer
MSG	= Metoesat Second Generation
NASDA	= National Space Development Agency (Japan)
NCDC	= National Climate Data Center
NDVI	= Normalised Difference Vegetation Index
NESDIS	= National Environment Satellite Data and Information Service (NOAA)
NGDC	= National Geophysical Data Center
NOAA	= National Oceanographic and Atmospheric Administration
NODC	= National Oceanographic Data Center
NOS	= National Ocean Service
NTIA	= National Telecommunication and Information Administration
NWS	= National Weather Service
OCTS	= Ocean Colour and Temperture Scanner
OPC	= Ocean Product Centre
OSSE	= Gamma-Ray Observatory Scintillation Spectrometer
SAGE	= Stratospheric Aerosol and Gas Experiment
SALT	= Savannas on the Long Term
SAR	= Synthetic Aperture Radar
ScaRab	= Scanner Radiatsionnovo Balansa
SCOSTEP	= Scientific Committee on Solar Terrestrial Physics
SEBEX	= Sahelian Energy Balance Experiment
SG 4	= Study Group 4
SIRTF	= Space Infrared Telescope Facility
SMMR	= Scanning Multichange Microwave Radiometer
SMY	= Solar Maximum Year
SOHO	= Solar and Heliospheric Observatory
SPOT	= Satellite pour l'observation de la Terre TMLF
SSM/I	= Special Sensor Microwave /Imager
SST	= Sea Surface Temperature
STEP	= Solar Terrestrial Energy Program
SUMER	= Solar Ultraviolet Coronograph Spectrometer
SWAN	= Solar Wind Anisotrophies
SWIR	= Short-wave Infrared Radiometer
TIMS	= Thermal Infrared Multispectral Scanner
TM	= Landsat Thematic Mapper
TOVS	= Tiros Operational Vertical Sounder
TRMM	= Tropical Rainfall Measuring Mission
UARS	= Upper Atmospheric Research Satellite
UNESCO	= United Nations Educational, Scientific and Cultural Organisation
USGS	= United States Geological Survey
VIRGO	= Variability of Solar Irradiance
WGD	= Working group on Data
WOCE	= World Ocean Circulation Experiment
WRCP	= World Climate Research Program

Apperdix

LIST OF CONTRIBUTORS

FOREWORD

The following report is a summary of progress made in certain scientific disciplines involved in space research. It was prepared by the Committee on Space Research in reponse to a request from the Scientific and Technical Sub-committee of the United Nations Committee on Peaceful Uses of Outer Space.

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